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Geotechnical risk decision tools for alternative project delivery method selection

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Geotechnical risk decision tools for alternative project delivery method selection

by

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NOMENCLATURE

DB	Design-Build
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
DBB	Design-Bid-Build
DBIA	Design-Build Institute of America
DOT	Department of Transportation
EDC	Every Day Counts
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
QM	Quality Management
RFP	Request for Proposals
RFQ	Request for Qualifications
TRB	Transportation Research Board
USAGE	U.S. Army Corps of Engineers

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ABSTRACT

Design-build (DB) geotechnical risk mitigation is an important concern for state departments of transportation (DOT), especially they seek to accelerate project delivery schedules. The nature of the DB delivery requires that projects are awarded before a complete subsurface has been done. Hence, projects are awarded without a comprehensive geotechnical scope, nor completed geotechnical design. DOTs are responsible for how mitigate the geotechnical risk during the procurement stage. Preliminary geotechnical investigation and geotechnical requirements are included in the request for proposals (RFP), and the goal of geotechnical risk allocation is to manage these risks. Based on the DOTs' position, design-builders' geotechnical risk perception is affected, and is reflected in their geotechnical risk contingency at the time of bidding the project. The worst scenario is when the DOT cannot award DB projects because projects are over budget.

The purpose of this study is to identify tools to manage geotechnical risk in DB projects by analyzing what types of geotechnical information should be included in DB solicitation documents. The study found a difference in the perception of geotechnical risk between DOTs when agencies were classified based on the level of their DB experience (those who have delivered more than 10 DB projects versus those that who delivered less than 10). Based on this classification, agency approaches in managing geotechnical risk were found to be different. As a result, the study proposes mitigation tools to assist DOTs to have a better geotechnical risk approach. Furthermore, the study found 27 geotechnical risks factors. These were identified based on an importance index whose purpose was to identify those factors that are more crucial in DB projects. The study benchmarked the perception of these geotechnical factors between DOTs and DB industry. Results showed that there is a significant difference between these two perceptions. In addition to this analysis, the study also found geotechnical factors that potentially could disqualify a project from being an ideal candidate for DB delivery.

The study was based on a comprehensive literature review; surveys of U.S. DOTs; case studies where potential geotechnical factors where identified; structure interviews of DOTs and a survey of DB industry. The results make it a useful document that records the tools to manage geotechnical risk in DB projects.

CHAPTER 1. INTRODUCTION

Design-build (DB) project delivery method has proven itself a viable method to accelerate the project delivery because it allows construction to begin before the geotechnical design is fully scoped (FHWA 2006). DB delivery also permits state departments of transportation (DOT) to transfer the responsibility for completing the geotechnical investigation necessary to support the geotechnical design to the design-builder after the award to the DB contract (Gransberg and Loulakis 2012). This creates a different risk environment than when the project owner has full responsibility for geotechnical design in a traditional design-build-bid (DBB) project. Competing design-builders bid the project based on how well DOTs manage the DB geotechnical risk profile during the procurement phase. A poorly documented DB contract, that sheds most if not all the subsurface risk forces the design-builders to include large contingencies in their bid prices to cover the geotechnical design assumptions it must make based on the information provided by the DOT in the request of proposals (RFP).

DB geotechnical risk emerges from two principal sources (Baynes 2010). The first is related to site underground conditions and technical risks associated with geological analysis and those associated with the engineering properties of the soils used in the analysis. This source is related to the identification of geotechnical risk factors encountered in DB projects such as groundwater issues or contaminated material. The second is related to geo-engineering process, including DB project management risks. The magnitude of DB project management risk are directly related to the scale of the preliminary geotechnical investigation made by the owner, the contract geotechnical risk allocation, and the quality of geotechnical information expressed in the RFP.

This thesis is focused on the impacts of geotechnical risk in DB projects, how these risk are managed by DOTs, and proposes viable alternatives to manage them. The first phase of the research was to benchmark the state-of-the-practice in quantifying pre-award geotechnical uncertainty. That analysis provided a point of departure for identifying the major geotechnical risk factors considered by both public agency and industry engineers to have a potentially significant impact on DB projects. A comprehensive assessment of these factors then led to the development of a prioritized geotechnical risk factors that should be addressed during the preliminary geotechnical engineering studies and prior to the award of the contract. Finally, since risk magnitude is a function of collective perception (Beecher et. al 2005) a comparison of perceived DB geotechnical risk between DOT and DB industry experts was conducted in order to determine those factors considered so risky that industry would either feel compelled to include excessively large contingencies in their bids or worse from the DOT perspective, choose not to pursue a DB project.

Content Organization

This thesis consists of a compilation of three different journal articles whose content and structure was selected to achieve the principal objective of the research mentioned above. Chapter 2 will provide the reader the necessary background information to understand the reminder of this study while Chapter 3 will detail the methodology used to complete the research.

The first article (Chapter 4) was submitted to the Transportation Research Board (TRB) and was accepted for presentation at the 2017 annual meeting, and publication in *Transportation Research Record, The Journal of the TRB.* This paper compares the differences in DOT geotechnical risk management practices, aspects of the DB procurement process, and contracts feature between experienced DOTs and non-experienced DOTs in delivering DB projects. This demonstrates the value of DB experience in managing geotechnical risk during the procurement phase and recommends practices for agencies that are new to DB project delivery.

The second article (Chapter 5) is will be submitted for publication in the American Society of Civil Engineers *Journal of Management in Engineering*. This article prioritizes DB geotechnical risk factors that should be addressed during the preliminary geotechnical studies and prior of the award of a contract. The classification of these factors will assist DOTs on how much and what type of preliminary geotechnical studies are needed to characterize a project's underground condition before the contract is awarded.

Finally, the third paper (Chapter 6) is also planned to be submitted for publication in the American Society of Civil Engineers *Journal of Management in Engineering.* This final article identifies and reports the differences between DOTs and industry perceptions of the impact of geotechnical factors in DB projects. The paper proposes alternatives for DOTs to mitigate geotechnical uncertainty in their DB solicitations.

CHAPTER 2. BACKGROUND AND MOTIVATIONS

This chapter presents information to provide a better understanding of geotechnical risks in DB projects. The information includes current practices used to manage geotechnical risk as well as some conclusions obtained from an exhaustive analysis of this information. This chapter complements and supports the following chapters. Finally, it describes the main reasons that led to the objective of this thesis, and the principal issue that is expected to be addressed with its completion.

Background

The Federal Highway Administration's (FHWA) Special Experimental Projects No. 14 (SEP-14): Alternative Contracting was introduced in 1990 and by 2009 more than 400 DB highway projects had been authorized (FHWA 2009). In June 2010, FHWA announced its Every Day Counts (EDC) initiative to address the rapid renewal of the nation's deteriorating infrastructure. The program is designed to accelerate the implementation of immediately available innovative practices (Mendez 2010). Hence, FHWA EDC encourages public owners the used of DB delivery as an approach of the program. The aggressive schedules common in DB project delivery creates a situation where the main focus of geotechnical engineers is shifted from the project's technical requirements to expediting the procurement process, and fosters a situation where geotechnical risks caused by inadequate geotechnical included in DB RFP and differing site conditions are managed after the award of the DB contract. In addition, because in DB delivery one entity is responsible for conducting design and construction, public agencies have less control over the everyday details of design progress, as both design and construction will have fixed obligations to meet a schedule and a price. This loss of control makes public agencies that are new to DB to fear that the project's quality will be degraded by implementing DB (Ernzen and Feeney 2002). As a consequence, explicitly implementing current effective practices to manage geotechnical risks prior of the award of the DB contract facilitate the achievement of the requisite level of quality in the finished product (Gransberg and Loulakis 2012).

Geotechnical conditions not only have an enormous impact on project design, but they directly impact project cost and schedule. One of the major issues during the procurement stage of a DB project relates to the accuracy and amount of geotechnical information is provided to the proposers to allow them to submit a competitive pricing without excessive contingencies to cover the risk of geotechnical uncertainties. This particular issue is aggravated by the fact that most DOTs use DB delivery to accelerate the delivery of a particular project (Songer and Molenaar 1996). Therefore, conducting a complete preliminary geotechnical investigation during the RFP development process is often impossible. For the above, it is essential that potential geotechnical risk factors be addressed during the preliminary investigation as a means of managing geotechnical risk.

The definitive quality of a DB project is most influenced during development of the request for qualifications (RFQ) and RFPs (Drennon 1998). The quality is most influenced during the early stages of project development. (Gransberg and Loulakis 2012). Quality management (QM) is a systems approach involving personnel, plans and procedures that describe the duties undertaken during planning, procurement, design, and construction to ensure that the final project complies with all the requirements agreed upon by the owner and the design-builder (Leahy et. al 2009). Practices such as geotechnical qualifications and past project experience of the proposers are means to manage geotechnical risk and should be given appropriate emphasis during the procurement phase.

Motivation

During the preliminary literature review for this research project, many studies were found addressing different types of issues associated with the selection of project delivery methods in the construction industry (Tran et.al 2013; Touran et.al 2011; Gad et.al 2015). However, none of the studies addressed the tools for selecting a contracting method as a function of the project geotechnical risk. Generally, DB contracting is used in many DOTs to accelerate the construction, reconstruction, and rehabilitation of transportation infrastructure due to the fact that it allows to start construction activities before having a 100% complete design (FHWA 2006). Additionally, in DB contracts, DOTs transfer to design-builders the responsibility for completing the necessary geotechnical studies to develop technical and price proposals as a part of the procurement process. If the DB team does not win, it may not recover the cost of those geotechnical studies or that the cost might exceed the stipend offered by the agency. DB contracts can be awarded before conducting a full geotechnical site investigation by either the owner or the design-builder (Smith 2001), forcing design-builders to adopt a different risk profile than when the project owner has full responsibility for the design (Gransberg and Loulakis 2012), as occurs in Design-Bid-Build (DBB) contracts. This risk profile involves the acceptance of a greater risk, which is reflected on higher expected profits to make the risk worth it, and higher contingencies to compensate for the greater level of uncertainty associated with the design.

As a result of an exhaustive literature review and a formal content analysis of previous studies and contract documents related to DB contracting and geotechnical investigation practices, a geotechnical risk assessment management tools will be developed to assist DOTs in the selection of project delivery methods. By factoring geotechnical risks into the process of selecting the project delivery method, DOTs potentially enhance their budget and schedule control by using the most appropriate contracting approach for the given geotechnical uncertainty at the time of contract award.

Problem Statement

Past research has shown that geotechnical risk might be the most difficult aspect of alternative delivery (Hatem 2011; Schaefer et.al 2011). Field factors, such as the risk of encountering differing site conditions, not only affect the project design, but if realized, also impact project cost and schedule. Therefore, the project delivery method selection decision demands that the owner identify and assess the geotechnical risk before making the decision. The same body of research also has shown that alternative contracting methods have been also been used as geotechnical risk management and mitigation tools (Gransberg and Gad 2014). To date there are no rational tools for determining if a given project's geotechnical risk profile makes it a good or bad candidate for alternative contracting. DOTs have increased their use of DB method in order to accelerate project delivery periods and share design risk with contractors (FHWA 2006) which includes geotechnical-related risk. In response to RFPs for DB projects, design-builders must submit technical and price proposals based on limited geotechnical information provided by owners at the time of advertising. This situation forces proposers to make assumptions about the geotechnical information not included in the RFP, increasing the project contingency found in price proposals. The proposed geotechnical risk assessment practices and tools developed in this research will assist DOTs in the project delivery methods selection decision.

CHAPTER 3. RESEARCH METHODOLOGY AND VALIDATION

Chapter 3 synthesizes the individual research methodologies used in the chapters 4, 5, and 6 and details the specific research instruments that were applied to each journal article's topic. This research employs both quantitative and qualitative research methods in order to develop the final product of the research. The research instruments are as follows:

- Literature review
- Survey
- Structure interviews
- Case studies

Following the subsequent chapter describes each instrument:

Literature Review

A comprehensive review of literature on managing geotechnical risk for highway projects was conducted in order to have a full spectrum to support the assertion that projects with significant geotechnical uncertainties should carry special attention during the procurement phase. The output of the literature review will be the base for development following research instruments. In order to complement the background and literature review in this chapter, additional literature review were performed for each journal article (Chapter 4, 5, and 6) within this thesis. Each journal article provided specific geotechnical literature review based on its particular topic.

Survey Methodology

The surveys conducted in during the development of this thesis involved on-line questionnaires. The surveys were developed based on survey methods suggested by Oppenheim (2000). The purpose of the surveys was to identify DOT policies and procedures for articulating geotechnical information and requirements on DB projects. The surveys also furnished real-time perceptional data regarding practitioner definitions of the importance geotechnical factors associated with geotechnical risk management on typical DB projects. The survey sought to identify successful approaches for managing geotechnical risks across the DB project's life cycle as well as discuss those practices that did not adequately address the geotechnical requirements and caused the agency to hold geotechnical liability that it had hoped to shed. Similarly, the purpose of a second questionnaire was to gauge the impact of geotechnical risk factors on DB projects. The obtained results were used to identify those geotechnical factors that could preclude a given project from being delivered using DB.

Structured Interviews

The structured interview questionnaire was based on the literature review, the content analysis of documentation and survey results. The structured interview methodology is prescribed for use when the study needs to face-to-face meetings probing participant responses, encouraging them to provide detail and clarification (Harris and Brown 2010). The interviews sought to identify and document effective practices to manage risk, such as the amount of preliminary geotechnical information conducted prior the award of the DB contract, which can be carried forward into the content of the tools.

Case Studies

Individual case studies were conducted on projects involving significant geotechnical risk on DB delivery method throughout the country. The case study protocol will follow the guidance provided by Yin (2008). Case studies are empirical inquiries that investigate contemporary phenomenon in its real-life context. The study believed to adequately evaluate how the various agencies have successfully implemented geotechnical risk management on projects delivered using alternative methods, case studies must be conduct. The case study protocol for the case study interviews and data collection plan included a research synopsis of objectives, projects, field procedures that detail the logistical aspects of the investigation, interview questions, and documentation to collect and a format for documenting and analyzing the individual case studies (Yin 2008). The case study protocol permits the research to conduct case studies separately in different parts of the country, while maintaining the reliability of the case study results. Internal validity was addressed by attending to multiple sources of evidence and the use of multiple case studies improved the external validity of the project delivery and project geotechnical management tools that may be identified as promoting project success.

CHAPTER 4. AN ASSESSMENT OF STATE AGENCIES' PRACTICES IN MANAGING GEOTECHNICAL RISKS IN DESIGN-BUILD PROJECTS

Castro-Nova, I., Gad, G.M., and Gransberg D.D., "An Assessment of State Agency Practices in Managing Geotechnical Risks," *Transportation Research Record*, *Journal of the Transportation Research Board,* National Academies, Paper 17-03399, (Accepted for presentation and publication in January 2017).

Abstract

State highways agencies policies and procedures for articulating geotechnical information and requirements on Design-Build (DB) projects is a means to manage geotechnical risks. Successful approaches and practices to managing geotechnical risk not only reduce the level of geotechnical uncertainty for both the owner and the competing design-builder, but also distribute the remaining geotechnical risk between the parties. This paper discusses the differences in regard to geotechnical risk management, aspects of the DB procurement process, and contract aspects between state departments of transportation (DOT) with experience delivering projects using DB versus those who are not as experienced. Results are presented from two independent sources of information; one was obtained through literature review of aspects related to geotechnical requirements and management of DB projects, and the other was through an online-survey of 38 DOTs. Results of the study statistically demonstrate the value of DB experience in managing geotechnical risks, and accordingly presents a set of recommended practices for agencies that are relatively new to DB project delivery, during both procurement and contract formation.

Introduction

For the past two decades, the courts have continually upheld the principle that construction project owners are liable for differing site conditions, regardless of the exculpatory language inserted into contracts in futile attempts to shed this risk (Loulakis and Shean 1996). Research has also shown that managing geotechnical risk in Design-Build (DB) projects may well be the most difficult aspect of alternative project delivery (Christensen and Meeker 2002*;* Clark and Borst 2002*;* Hatem 2011*;* and Schaefer et.al 2011). Not only is DB selected by public owners for those projects that need accelerated schedules (Songer and Molenaar 1996), but the geotechnical exploration, design, and construction activities are also the first tasks that must be completed as the DB project starts, making them the ones with little or no float (Smith 2008).

Therefore, combining DB delivery of a project that includes significant geotechnical uncertainty can easily create the "perfect storm" of risk, and as such, demand that public agencies give the geotechnical aspects of a given project more early attention than a typical project (Gransberg and Loulakis 2012).

The Federal Highway Administration's (FHWA) Special Experimental Projects No. 14 (SEP-14): *Alternative Contracting* was introduced in 1990 and by 2009 more than 400 DB highway projects had been authorized (FHWA 2009). In June 2010, FHWA announced its *Every Day Counts* (EDC) initiative to address the rapid renewal of the nation's deteriorating infrastructure. The program is designed to accelerate the implementation of immediately available innovative practices (Mendez 2010). DB project delivery has proven itself to be one method to accelerate the construction, reconstruction, and rehabilitation of aging, structurally deficient infrastructure because it allows construction to begin before the geotechnical design is fully complete (FHWA 2009). DB also allows agencies to shift some of the responsibility for completing the geotechnical investigations necessary to support the geotechnical design to the design-builder after the award of the DB contract (Gransberg and Loulakis 2012). However, in addition to these benefits, there may be some disadvantages that can arise if the contract is poorly documented, particularly related to the management and allocation of subsurface risk between the owner and contractor (Dwyre et.al 2012).

Many studies have addressed the need to identify, quantify, and mitigate geotechnical risk during the procurement phase of DB projects (Christensen and Meeker 2002). Daoulas (2011) addresses key elements that should be considered regarding geotechnical risk during the proposal preparation phase. Another study suggests effective practices, such as enhancing communication between the owner and the design-builder, the use of differing site conditions clauses, and expediting geotechnical design reviews after the contract is awarded, can be employed to mitigate/reduce the geotechnical risk (McLain et.al 2014). Likewise, other studies have concentrated specifically on the legal aspects of DB geotechnical issues (Papernik and Farkas 2005). According to the NCHRP Synthesis 429: *Geotechnical Information Practices in Design-Build Projects,* the design-builder is entitled to rely on the geotechnical information contained in the DB Request of Proposal (RFP), and the DB contract's differing site condition (DSC) clauses furnish a mechanism under which the design-builder can claim compensation for additional cost and time if the RFP does not reasonably match the actual conditions (Gransberg and Loulakis 2012).

The purpose of this paper is, thus, to identify and report the differences among agencies' perceptions toward managing geotechnical risks in DB projects, and accordingly present a set of recommended practices for agencies that are relatively new to DB project delivery. DOTs were divided based on the total number of DB projects that the agencies have delivered. The information comes from a comprehensive literature review supplemented by manuals or documents that the respondents attached in their responses in regard to information that specifically describes the procedures to be used with geotechnical requirements of DB projects, and the output from a survey that sought to identify successful approaches to managing geotechnical risk. The paper will report the variations in the approaches used for DB geotechnical risk management and how those relate to the DB procurement process. It will then compare DB contracting procedures between experienced and non-experienced DOTs.

Background

Because of the need to accelerate the delivery schedule of transportation projects (FHWA 2009), DB project delivery has grown steadily over time. With the EDC initiative that proliferated DB project delivery, currently 47 states implemented DB in their highway projects (DBIA 2013), yet many DOTs still lack DB experience and have encountered issues dealing with potentially high levels of geotechnical uncertainty during the procurement phase. Thus, effective practices to deal with geotechnical risk during the procurement phase are essential to ensure the quality of the final constructed project. "It is during the development of the Request for Qualifications (RFQ) and RFP that the ultimate quality of the project can be most influenced" (Drennon 1998, Gransberg and Loulakis 2012). During procurement phase and beginning of the design phase, quality is the most influenced and then falls off during next stages such as construction and maintenance (Gransberg and Loulakis 2012). Quality management (QM) is a term that describes the tasks undertaken during the planning, procurement, design, and construction to ensure that the final project conforms all the requirements agreed upon by the owner and the construction contractor (Leahy et.al 2009). In a DB delivery projects, QM is implemented using a systems approach involving three primary components (Smith 2001, Panchmatia 2011): 1) personnel, 2) plans, and 3) procedures.

According to DOT surveys conducted for NCHRP Syntheses 376 and 429 (Gransberg et.al 2008, Gransberg and Loulakis 2012), the qualifications of the members of the DB team and its past projects experience were rated as having the most impact on final projects quality. The qualifications of the design-builder's geotechnical engineers and their past experience with project-specific geotechnical issues are also key to achieving quality in the constructed DB project (Gransberg and Loulakis 2012; Rueda-Benavides and Gransberg 2014). Additionally, appropriately weighting geotechnical evaluation factors with regards to all evaluated factors is also essential to selecting the best DB team for a given project (Gransberg and Loulakis 2012). NCHRP Synthesis 429 found two methods for assigning weight to evaluation criteria. The first consists of assigning a specific number of points to each evaluation criterion with the ratio of individual criterion's point score to the total available points for the entire evaluation representing its weight to the other evaluation criterion. The second method weights each evaluation category in parallel with the objective of the project (Gransberg and Loulakis 2012). The synthesis concludes that the weight of geotechnical factors must be assigned according to the other factors that define success for a given DB project. A subsequent study suggested that the geotechnical content of the RFP must be tailored for each project (Gransberg and Gad 2014; Lee et.al 2016).

A successful DB project depends on a well-written, unequivocal RFP that contains the required information for competing design-builders to prepare approachable proposals that impartiality price the value of the DB project's scope of work and the risk associated with competing that work (USACE 2009). In addition, the amount of geotechnical information expressed in the procurement phase plays an important role over the probability to a given DB project ends in a DSC claim. McLain et al. (2014) found that providing all the geotechnical information on hand when the project is advertised and forming the DSC clause in a manner that makes it specific to the available geotechnical data instead of using a standard DBB boilerplate DSC was an effective alternative to manage geotechnical risk.

There are four principal areas of the project's solicitation documents that can be addressed in a typical DOT's DB procurement process and that was used by the researchers to identify and evaluate the DOT's geotechnical risk management practices.

1. The geotechnical qualifications for key personnel in the request of proposal (RFP);
2. Specific geotechnical design and construction experience evaluation criteria;

3. Inclusion and weighting of geotechnical evaluation criteria in the proposal evaluation plan, and
4. Geotechnical information requirements required by the RFP to be included in competing proposals (Gransberg and Loulakis 2012).

Research Method

The study's methodology relied on two independent research instruments. The first instrument was a comprehensive review of literature on managing geotechnical risks in DB projects. The literature review focused on current DOTs processes used regarding geotechnical requirements of DB projects and it included review of DOT risk management manuals.

The second instrument was an online-survey whose purpose was to identify DOT policies and procedures for articulating geotechnical information and requirements on DB projects. The survey was initially issued to the members of the AASHTO Subcommittees on Construction and Design in each of the 50 DOTs. The subcommittee members were asked to then forward the survey to the person best-qualified to respond on an overall department basis. Responses were received from 38 DOTs yielding an overall response rate of 76%. Around 80% of the respondents either work in the department's geotechnical/foundations section. Hence, the survey results reflect the perceptions of the most technically qualified group in each agency.

Analysis and Results

As detailed in the methodology, the analysis of the survey sought to investigate the differences between experienced and non-experienced DOTs in regard to geotechnical factors. Results of the survey was analyzed using both descriptive and inferential statistics, and was divided into responses from experienced versus non-experienced DOTs as shown in Table 1. The inferential statistics implicated hypotheses testing with the Pearson chi-square to determine whether there is statistically significant difference in the perception of DB projects' geotechnical factors/areas adopted by agencies. The descriptive statistics included the findings of the geotechnical requirements and management approaches online-survey. Table 1 shows the locations and the positions at the time of the online-survey.

TABLE 1. Survey respondent and categorization based on experience in DB projects

Category	**Responding States**
Experienced DOTs *(>10 DB projects)*	Arizona, California, Colorado, Georgia, Kentucky, Maine, Maryland, Michigan, Minnesota, Missouri, Montana, New York, North Carolina, Ohio, South Carolina, Utah, Virginia, Washington, West Virginia
Non-experienced DOTs *(<10 DB projects)*	Connecticut, District of Columbia, Hawaii, Kansas, Louisiana, Massachusetts, Nevada, New Hampshire

Comparison of Perceptions

"Geotechnical engineering is fundamentally about managing risk" (Ho et.al 2000). Even though geotechnical risk cannot be eliminated from DB projects, it can be better managed by appropriately allocating the risk between the owner and the design-builder (Molenaar et.al 2000). Differing geotechnical conditions are conditions that materially differ from what the contractor should have reasonably expected when it priced its contract (Gransberg and Loulakis 2012). Many DOTs believe that contractors should assume full risk of differing site conditions (Christensen and Meeker 2002). However, the results of the online-survey for this research show that not all agencies share the same thought. Particularly, the study found that experienced and non-experienced DOTs allocate unknown geotechnical conditions differently. Experienced agencies are defined as those having completed more than 10 DB projects and they tend to share geotechnical risk; whereas non-experienced agencies tend to either accept or shed all of it. NCHRP Synthesis 429 concluded that the emphasis on formal risk analysis before selecting DB project delivery differentiates experienced and non-experienced DOTs (Gransberg and Loulakis 2012).

In terms of weight of geotechnical factors, Figure 1 shows a comparison of experienced versus non-experienced DOTs in terms of their perception of geotechnical factors weight with regard to all other evaluated factors if they are included in the DB project's evaluation plan. It is seen that while more than 80% of non-experienced DOTs agree that geotechnical factors have No/Minor weight in their evaluation plans, more than 60% of experienced place a Some/Heavy weight to geotechnical factors. This shows how experienced DOTs, in general, are more aware and realize the importance of the geotechnical factors in the evaluation plan on DB projects.

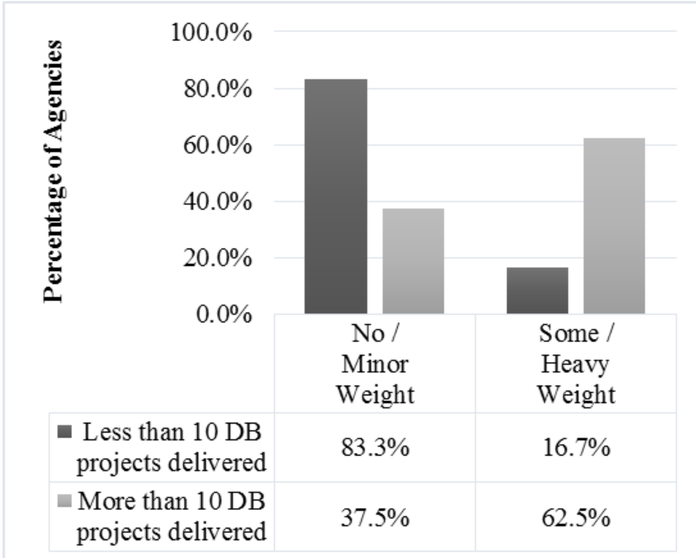
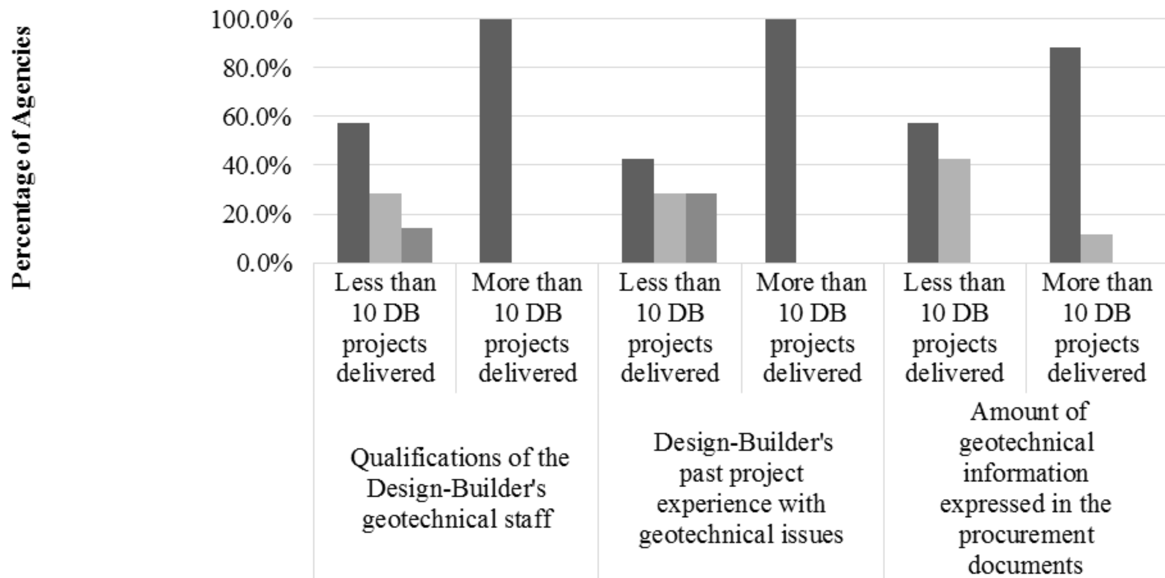


FIGURE 1: Geotechnical Evaluation Criteria Weighting.

As for the three geotechnical factors shown in Figure 2 in terms of their impact on the final quality/performance of the DB project, a consistent difference is observed in the higher consideration of experienced DOTs of these factors compared the non-experienced DOTs. For instance, 100% of experienced DOTs not only agree in rating the qualification of the design-builder's geotechnical staff as a very/high impact, but also agree in rating the design-builder's past project experience with geotechnical issues as very/high impact. In contrast, non-experienced DOTs results are dispersed across the range of impacts. Non-experienced DOTs do not perceive the importance of qualifying the design-builder's geotechnical experience and workforce as being as important as the experienced DOTs. Experienced DOTs see the amount of geotechnical information included in RFPs as important to decreasing geotechnical uncertainty during procurement, which can make proposals received more competitive (Christensen and Meeker 2002).



	Qualifications of the Design-Builder's geotechnical staff: Less than 10 DB projects delivered	Qualifications of the Design-Builder's geotechnical staff: More than 10 DB projects delivered	Design-Builder's past project experience with geotechnical issues: Less than 10 DB projects delivered	Design-Builder's past project experience with geotechnical issues: More than 10 DB projects delivered	Amount of geotechnical information expressed in the procurement documents: Less than 10 DB projects delivered	Amount of geotechnical information expressed in the procurement documents: More than 10 DB projects delivered
Very High/ High Impact	57.1%	100.0%	42.9%	100.0%	57.1%	88.2%
Some Impact	28.6%	0.0%	28.6%	0.0%	42.9%	11.8%
Slight/No Impact	14.3%	0.0%	28.6%	0.0%	0.0%	0.0%

FIGURE 2: Impact of Geotechnical Risk Factors

Another interesting difference between experienced and non-experienced DOTs is related to the allocation of geotechnical uncertainty. Figure 3 illustrates that while 57% of experienced DOTs are more willing to share the subsurface risk uncertainty rather than bear it, more than 50% of non-experienced DOTs are willing to bear the risk rather than share it, and only 14% of these DOTs allocate it to the owner. Thus, experienced DOTs tend to share the risk or bear it, while non-experienced DOTs’ tendency is to either take or shed the risk. This could be attributed to the better understanding of the DB project delivery method as compared to the traditional methods in terms of risk allocation.

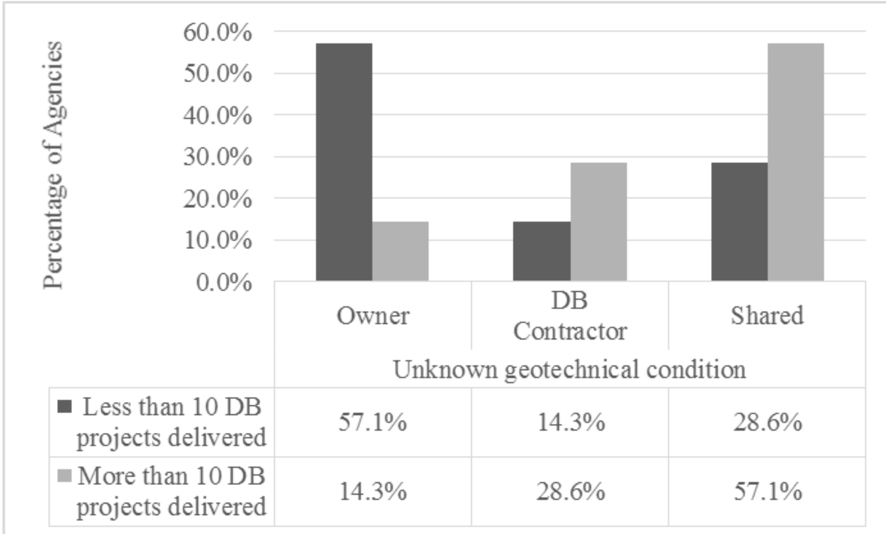


FIGURE 3. Geotechnical Risk Allocation

Finally, Figure 4 shows the other prominent difference between experienced and non-experienced agencies which was the perception of the level of importance of completing a formal geotechnical risk. Over 70% of experienced DOTs rated a formal geotechnical risk analysis as either "important" or "very important," while 50% of non-experienced DOTs gave the formal analysis of geotechnical risk no importance.

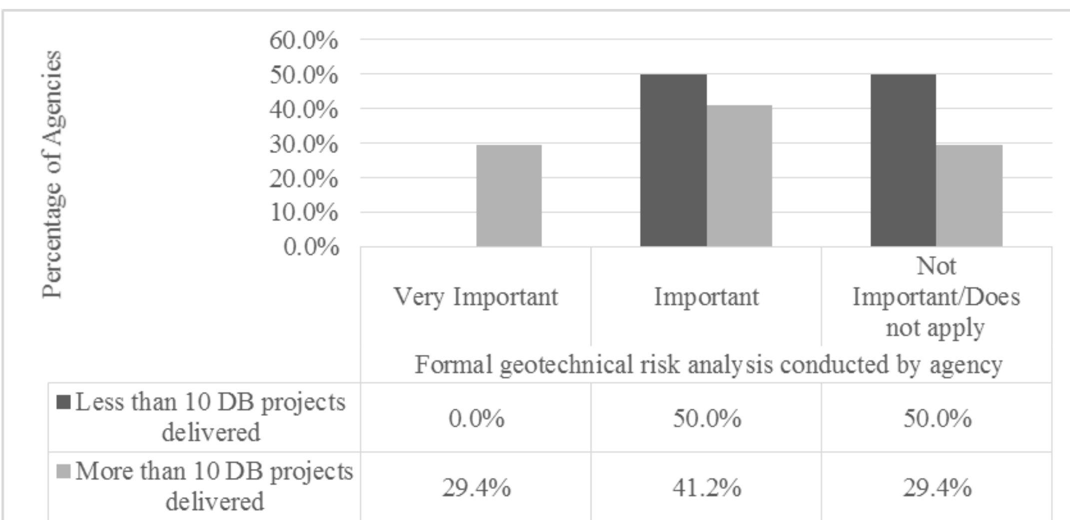


FIGURE 4: Formal Geotechnical Risk Analysis

A statistical analysis was further conducted using the Pearson Chi-Square Test to if there is a statistical significant difference in the perception of DB's geotechnical aspects between the two groups. The Pearson Chi-Square Test is a statistical technique that can be used both as a test of goodness of fit and as a test of independence (McDonald 2009).The independence test is used to determine whether two categorical variables are associated with one another (Runyon et.al 2002, Gad et.al 2015). Thus, in this study, Pearson Chi-Square Test of independence was used to determine whether there is a significant difference between the perception of experienced and non-experienced DOTs in evaluating geotechnical factors in DB projects during the procurement phase. Table 2 shows the different aspects tested; for example, the hypotheses tested for design-builder's geotechnical staff qualifications was:

H_{o1}: There is no statistical difference between experienced and non-experienced DOTs in their perception of design-builder's geotechnical staff qualifications on the final quality/performance of the DB project.

H_{a1}: There is a statistical difference between experienced and non-experienced DOTs in their perception of design-builder's geotechnical staff qualifications on the final quality/performance of the DB project.

TABLE 2. Summary of Chi-Square Test Results for Experienced versus Non-experienced DOTs

Aspects tested	**Chi-Square (χ^2)**	**Significance (*p*)**
Impact of the design-builder's geotechnical staff qualifications on DB project quality/performance.	8.327	0.01*
Impact of the design-builder's past project experience with geotechnical issues on DB project quality/performance.	11.657	0.00*
Impact of the amount of geotechnical information expressed in the procurement documents on DB project quality/performance.	2.906	0.08
Geotechnical factor weighting in the evaluation plan compared with other evaluation factors	3.667	0.05
Unknown geotechnical condition risk allocation	4.200	0.12
Formal geotechnical risk analysis conducted by agency	2.385	0.30

As per results shown in Table 2, the following two hypotheses tested were statistically significant:

- Qualifications of the design-builder's geotechnical staff ($\chi^2 = 8.32\ and\ p - value = 0.01$). The null hypothesis was rejected given that *p-value* < 0.05. Thus, there is a statistically significant difference between how experienced and non-experienced DOTs perceive the impact of qualifying design-builder's geotechnical team on the final performance of the DB projects, with experienced DOTs putting more weight on the geotechnical staff experience.
- Design-Builder's past project experience with geotechnical issues ($\chi^2 = 11.65\ and\ p - value = 0.00$). The null hypothesis was rejected given that *p-value* < 0.05. Hence, there is a statistically significant difference between experienced and non-experienced DOTs in rating the design-builder's past project experience with geotechnical issues on the final performance of the DB projects.

The remaining aspects were tested and the hypothesis was accepted, with no statistically significant difference in the perceptions of experienced and non-experienced DOTs.

Conclusions and Recommendations

This paper's main objective was to investigate the differences between DOTs experienced and non-experienced in delivering DB projects' in regard to geotechnical risk management, aspects of design-build procurement process, and aspect of design-build contracts. Experience was measured by the number of DB projects delivered. Through an online survey administered to State transportation agencies, it was evident that DOTs with more experience in delivering DB projects viewed and handled geotechnical risks differently. The significant difference was observed in the importance of the qualifications and past experience of the design-builder's geotechnical staff. Another relevant difference was in the degree of impact of the design-builder's past experience with project-specific geotechnical issues. Furthermore, the paper finds that experienced DOTs allocated unknown geotechnical condition risk differently than non-experienced DOTs. Experienced DOTs tend to share unknown geotechnical conditions risk while non-experienced DOTs either allocate all the risk to the owner or attempt to shed it. Also, experienced DOTs do understand the importance of providing as much geotechnical investigation information as possible during the procurement process to reduce uncertainty as much as possible during bidding. Non-experienced DOTs opinions are spread across the spectrum of possible options.

Bringing the above discussed findings into the context of the problem at hand, the study furnishes its main contribution by statistically demonstrating the value of DB experience in managing geotechnical risk. The results can be summarized into the following set of recommended practices for agencies that are new to DB project delivery.

- The qualifications and past experience of the design-builder's geotechnical staff is important to successfully managing geotechnical risk and as such, should be given appropriate emphasis during the procurement process.
- A formal geotechnical risk analysis affords the DOT project staff the ability to identify, quantify and mitigate the geotechnical risk before the procurement process starts and thus adds value to the DB project delivery process.
- Uncertainty is reduced by increasing the amount of information available at the time a decision is made. Therefore, the DOT should provide as much information on subsurface conditions as it has at the time the DB project is advertised to permit competing DB teams the greatest information benefit as they make risk pricing decisions during bidding.
- The cost of geotechnical uncertainty at the time of bidding can be mitigated by the thoughtful allocation and sharing of project-specific geotechnical risks in the DB RFP.

As mentioned in the paper's first section, US case law shows that the owner cannot fully shed geotechnical risk by relying on exculpatory DSC clauses alone. Therefore, this risk must be confronted early in the project development process, producing thoughtful geotechnical risk management plans that rationally share the project-specific risks with the competing design-builders during procurement and after award of the DB contract.

CHAPTER 5. IDENTIFICATION OF POTENTIAL GEOTECHNICAL RISK FACTORS IN DESIGN-BUILD TRANSPORTATION PROJECTS

Castro-Nova, I., Cetin, B., and Gransberg D.D., "Identification of Potential Geotechnical Risk Factors in Design-Build Transportation Projects" *Journal of Management in Engineering*, ASCE (to be submitted).

Abstract

Subsurface conditions in Design-Build (DB) projects is an inherent risk given the nature of this delivery method. Since the contract is frequently awarded before the agency has an opportunity to complete the necessary subsurface investigation need to support the geotechnical design, state departments of transportation (DOTs) and the DB industry must cope with a high level of geotechnical uncertainty during the procurement process. The purpose of this research is to assists DOTs to prioritize geotechnical risk factors that should be addressed in the preliminary studies and request of proposal (RFP). This paper identifies 27 geotechnical risk factors and proposes a prioritized list based on each factor's frequency and impact using importance index theory to objectively rank the factors using data from 46 DOT and industry experts. The paper finds that geotechnical risk is not considered a bar to DB delivery and as such, must be addressed in the DB solicitation. The paper's contribution is the ranked factors which can be used as a checklist when developing DB procurement documents.

Introduction

In 1990, the Federal Highway Administration (FHWA) introduced its Special Experimental Projects No. 14 - Alternative Contracting (FHWA 2009) and by 2009 had authorized more than 400 DB projects. In 2010, FHWA initiated the Every Day Counts program to address the need to rapidly renew the nation's deteriorating infrastructure (Gransberg and Loulakis 2012). According to a report from the Design-Build Institute of America (DBIA), more than 44 states have authorized DOTs' to use DB in their transportation projects (DBIA 2010). Based on a study conducted by the FHWA, public transportation agencies have found that they can accelerate project delivery schedule by implementing DB delivery method (FHWA 2006). During the DB procurement phase, the state DOT articulates the project's scope of work, releases the request for proposals (RFP), accepts and evaluates the proposals received, and selects a design-builder to design and construct the project. However, the speed of DB project preliminary engineering and procurement phase often is not long enough to conduct a thorough subsurface investigation as done in a traditional design-bid-build (DBB) project (Dwyre 2010). Therefore, the scope of work for most DB contracts typically requires the design-builder to conduct a comprehensive geotechnical investigation as part of the design phase. Furthermore, since design-builders are typically required to bid a firm fixed price before a completing the geotechnical investigation they must include sizeable contingencies to cover not only the assumptions made in the preliminary geotechnical design, but also to cover the probability of having differing site conditions (Lopez del Puerto et. al 2016).

"Geotechnical conditions not only have an enormous impact on project design, but also directly affect project cost and schedule" (Gransberg and Loulakis 2012). Similarly, subsurface conditions and their influence on underground construction such as foundations and earthwork, are inherent risks to which all parties to the contract are (Dwyre 2012). DOT RFP packages must provide proposing design-builders with adequate underground information to allow proposers to produce conceptual designs for the foundations, embankments, and other features of work that are dependent on the geotechnical conditions site so that a lump sum price can be fixed for the bid. If the underground project information is inadequate, then the proposing design-builder firm has two options (Christensen and Meeker 2002). The first is to include a large contingency in the proposed price to cover the worst possible case. The other is to not bid if it perceives the level of geotechnical risk as unacceptable (Dwyre 2010). Either approach negatively impacts the DOT DB project. In the first case, the contingency could drive the price outside the available budget making the contract impossible to award, and in the second case the owner (DOT) is in danger of awarding the DB contract to a competitor that does not recognize the actual magnitude of the geotechnical scope risk, which potentially exposes the DOT to either a major differing site conditions claim or a design-builder that has underpriced the geotechnical scope and is in financial difficulties. In this environment, addressing geotechnical risk factors during the preliminary study and prior to award of the contract plays a critical role in the procurement of a DB contract. Although transportation research in managing geotechnical risk have studied geotechnical requirements during the procurement phase, no previous studies identified by researchers have focused on developing a prioritized list of geotechnical factors that should be addressed before a DB project is advertised.

The objective of this paper is to assist DOTs during the preliminary engineering stage of DB RFP development to decide how much pre-advertising geotechnical investigation should be conducted by providing a list of geotechnical factors prioritized by their impact and frequency that should be addressed in the RFPs. The research's scope is limited to DB projects. The information comes from a comprehensive literature review of previous research and DOT DB manuals, the results of two online-surveys that sought to identify geotechnical factors that are encountered during the execution of a DB project, and case study structured interviews with DOT and industry experts. The paper will propose a prioritized list of geotechnical factors that should be addressed during the procurement phase of a typical DB project.

Background and Point of Departure

Typically, during the procurement phase of a DB project, the information regarding the project's geotechnical scope is limited. This issue is because most public owners choose DB project delivery to accelerate the delivery process of a given project (Songer and Molenaar 1996). Therefore, the preliminary geotechnical investigation included in the RFP is not often a complete document describing the actual underground's characteristics (Beard et. al 2001). The DOT's RFP packages must provide sufficient subsurface information to permit competing design-builders to generate conceptual designs for underground structures and price them. When the RFP geotechnical information is inadequate, DOTs are exposed to potential differing site conditions claims because the actual geotechnical scope was not the same as described in the DB contract.

Based on the DOT's ability to accurately portray the geotechnical scope, the project delivery method selection decision should include an analysis of the subsurface investigation and geological conditions. The descriptive analysis of two surveys questionnaires responses from NCHRP Synthesis 429: *Geotechnical Information in Design-Build Projects* and NCHRP 24-44: *Guidelines for Managing Geotechnical Risk in Design-Build Projects*, show that geotechnical risk considerations do not prevent DOTs from choosing DB project delivery of transportation projects. This trend is supported by the formulated question in both surveys' questionnaires. Is it noted that the same formulated question was issued in 2011 and then in 2016. Figure 5 shows the tendency of agencies regarding the use of DB delivery method where the geotechnical risks are considered to be significant.

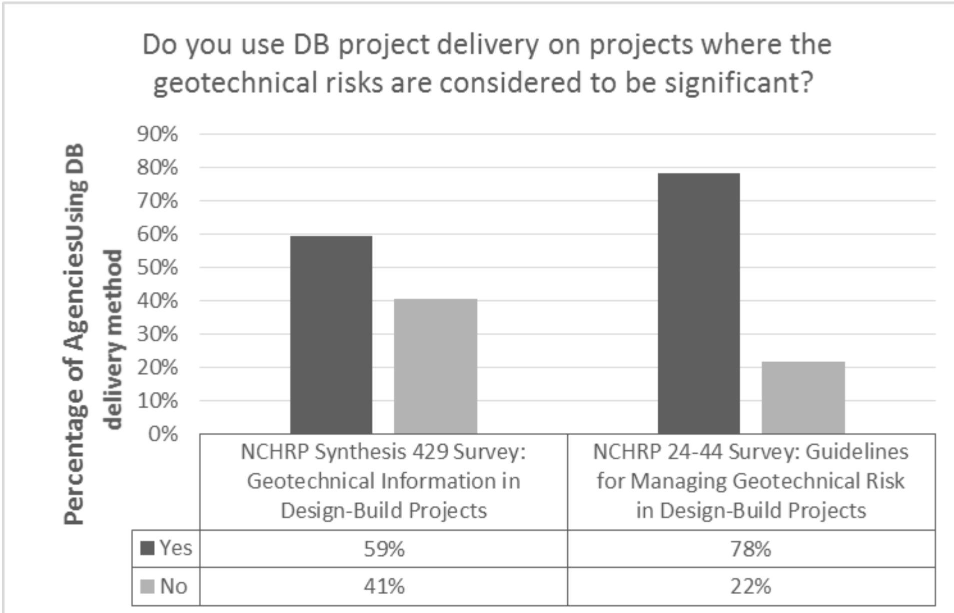


FIGURE 5. Use of DB Delivery where Geotechnical Risk is Considered to be Significant

Similarly, the trend indicating that geotechnical risk does not normally influence the decision to utilize DB is supported when survey respondents were asked to name potential reasons for not selecting DB delivery when the geotechnical risks were perceived to be significant. Figure 6 illustrates the total number of agencies obtained by examining both surveys.

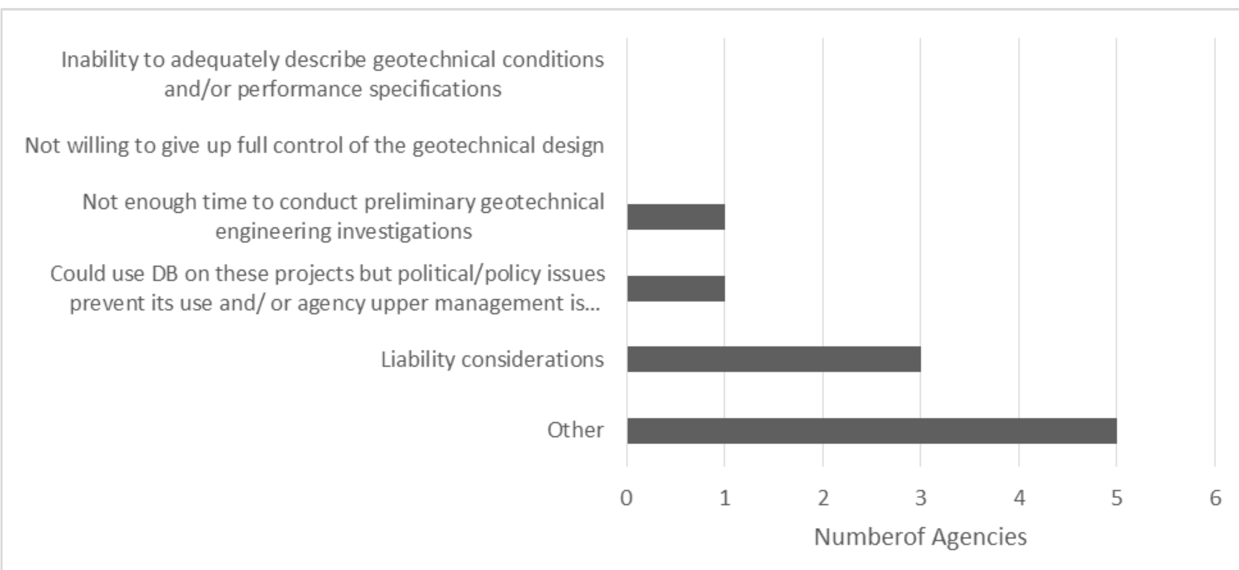


FIGURE 6. Reasons why agencies do not use DB projects delivery when geotechnical risk is significant.

As it is shown in the Figure 6, “other” reason was the most common option selected. There were three main responses from DOTs which are the followings:

1. DB projects are mainly governed by schedule and funding, instead of geotechnical risk
2. Geotechnical risk is generally not a consideration because the decision to use DB is made well before any geotechnical investigations is conducted,
3. Geotechnical aspects are not the main factors in determining the project delivery method.

Based on these responses and the figures above, it can be concluded that geotechnical risks do not influence the decision to use DB delivery for a given project. However, as mentioned above, differing site conditions have a large influence on the schedule and cost of a DB project, which leads one to infer that these risks have a place in the project delivery method selection decision. As such, a tool to assist in evaluating the geotechnical risk’s potential impact to project success would add value to the project delivery method decision-making process.

The literature review indicated that little research has been done to investigate which specific geotechnical risk factors should be addressed in the preliminary engineering effort for DB projects. Some studies explored factors that impact selecting DB delivery. Tran et.al (2013) identified seven risk factors that have the most influence on DB delivery method. It is noteworthy that geotechnical component from construction risk was found to be the third most important factor. Likewise, Tran et.al (2012) found four risk factors that have the most influence related to the project delivery selection process. Once again, geotechnical investigation is one of the four risk factors. Other studies have suggested strategies regarding geotechnical contract provision for DOTs and design-builders. Dwyre et al. (2010) concluded that the geotechnical elements of the contract documents must be integrated, including design criteria, plans, geotechnical reports, and technical specifications. Jaksa (2000) recommends that the site investigation be carried in two phases, preliminary and detailed investigation, and that the uncertainty associated with the recommended design parameters should be expressly stated. Finally, Daoulas (2011) proposes that geotechnical risks should be assessed during the procurement phase and prior to award of the contract by generating a geotechnical engineering data report.

Given that the surveys found that geotechnical risk does not drive the DB delivery decision and that the literature review was sparse on information on how geotechnical risk factors should be identified prior to the award of the DB contract, the researchers made identifying the most common geotechnical factors encountered during the execution of DB projects the point of departure for the study. The study proposes a list of geotechnical risk factors that DOTs should address during the preliminary geotechnical investigation of a DB project.

Research Method

In order to achieve the research objective an online-survey questionnaire was selected as the primary research tool. The research aims were reached in three phases. First, identification of geotechnical factors from an online-survey was completed; secondly, geotechnical factors found in the literature review and other external resources were compiled; and third, a second survey of DOT and industry experts was conducted to collect geotechnical factor impact and frequency to provide the necessary data to develop an objective ranking of those factors based on Importance Index theory (Assaf and Al Hejji 2006).

Identification of Geotechnical Risk Questionnaire

The first step consisted in the survey data collection effort focused on determining the frequency of eleven common elements of subsurface uncertainty typically found on DB projects, based on the literature. Each factor’s frequency of occurrence was collected from the results of the survey. The survey’s overarching objective was to identify state highway agency policies and procedures for articulating geotechnical information and requirements on DB projects. The survey was sent to the 41 members of the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Material’s Technical Section 1b – Subsurface Exploration. The survey had a 53% response rate. Figure 7 shows the results of the online survey.

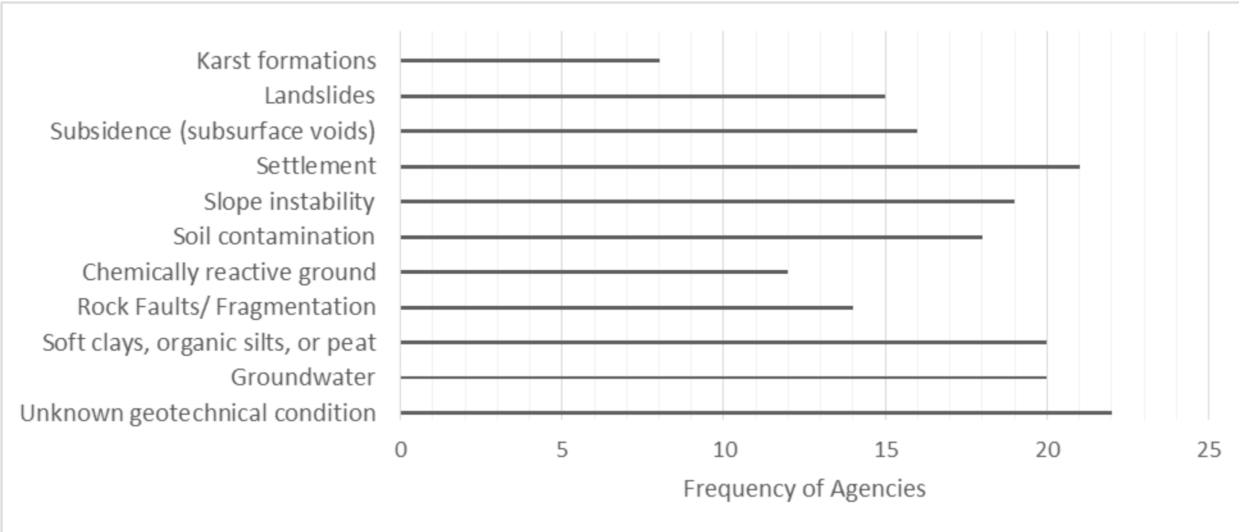


FIGURE 7. Geotechnical Risks in DB Projects

Compiling Geotechnical Factors in DB Projects

In the second step a content analysis of DOT geotechnical design manuals was conducted and combined with data from subject matter experts interviewed in conjunction with the development of agency case studies. The result was an expanded list of 27 final geotechnical factors. Two examples of the documents reviewed is the content analysis are *Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications* (FHWA 2003) and the *GeoConstructability Report* (GeoConstructability 2011). These were used to identify geotechnical factors that were not included in first 11-factor list. Case studies interviews and an analysis workshops on more than $3 billion in transportation projects provide additional input to the final of 27 geotechnical factors by adding potential DB-specific risks.

DB Geotechnical Factors Assessment Questionnaire

The second online-survey questionnaire was sent to DOTs and geotechnical professionals with DB industry experience. Because of the highly specific information sought in the second survey, a pilot questionnaire was sent to one DOT and one industry expert to test the understandability and clarity of the survey. The pilot test resulted in important modifications to the questionnaire. The revised questionnaire was then deployed to the DOT and industry target populations. A total of 46 valid responses were received from 22 DOTs and 24 industry experts, yielding an overall response rate approximately 31%. The second survey asked respondents to rate the frequency of 27 risk factors on DB transportation projects using a Likert scale ranging from never occurs (0) to occurs very often (4) for frequency of occurrence as well as impact on a Likert scale from no impact (0) to catastrophic impact (4).

Analysis and Results

The analysis of the data was conducted in accordance with Importance Index methodology (Assaf and Al Hejji 2006; Santoso and Soeng 2016). This approach requires the analyst to initially calculate a frequency index and an impact index based on the perceptions of the expert survey respondents. These are then combined mathematically to calculate an importance index for each factor. The underlying theory is that a risk with a high impact that frequently occurs is more important than a low impact risk that rarely occurs.

The approach prosed by Assaf and Al Hejji (2006) was adapted for use in this specific context. The Importance Index, is a function of the Frequency Index (FI) and Impact Index (II). The indices are computed as shown in equations 1, 2, and 3 below:

Frequency Index: This formula was used to rank the geotechnical factors based on the frequency of occurrence as indicated by the contestants

$$Frequency\ Index\ (FI)(\%) = \sum a\left(\frac{n}{N}\right) * 100/5 \qquad \text{(Eq. 1)}$$

Where a = is a constant defining the weighting assigned to each response (ranges from 0 for Never up to 4 for Very Often), n = is the frequency of the responses, and N = is the total number of responses.

Impact Index: This formula was used to rank the geotechnical factors based on the impact of as indicated by the contestants

$$Impact\ Index\ (II)(\%) = \sum a\left(\frac{n}{N}\right) * 100/5 \qquad \text{(Eq. 2)}$$

Where a = is a constant defining the weighting assigned to each response (ranges from 0 for No Impact up to 4 for Catastrophic impact), n = is the frequency of the responses, and N = is the total number of responses.

Once having these two indices the Importance Index can be calculated by the following formula:

$$Importance\ Index\ (IMPI)(\%) = [F.I.(\%) * I.I.(\%)]/100 \qquad \text{(Eq. 3)}$$

The indices explained above were then used to objectively rank geotechnical risk factors in DB projects. Table 3 presents the 27 geotechnical factors.

TABLE 3. Geotechnical Factors/Risks in DB Projects

FACTORS/RISKS	
Groundwater/ Water table	Replace in situ material with borrowed material
Soft clays, organic silts, or peat	Ground water infiltration
Highly compressive soils	Caverns/voids
Rock Faults/ Fragmentation	Soft compressible soil
Chemically reactive ground	Underground manmade debris
Contaminated material	Settlement of adjacent structure
Slope instability	Sensitiveness of public consideration (Parks, historic building, etc.)
Seismic Risk	Eroding/mobile ground conditions
Lateral spreading	Existing structures likely to be impacted by the work (other than utilities)
Liquefaction	Presence of rock/boulders
Settlement in general	Unsuitable material
Settlement of bridge approaches	Karst formations
Subsidence (subsurface voids)	Scour of bridge piers
Landslides	

It must be noted that while it is possible to compare the perspectives of DOT respondents with those of the industry experts, the objective is to rank the importance of common factors. Therefore, the remaining analysis uses the responses as a single population. Comparing the two groups is out of the scope of this paper, but will be undertaken in a future paper. The following section describes the rationale regarding the results of importance index.

Frequency of Geotechnical factors

The Top-27 frequent factors from the survey are shown in Table 4. Results were compared against the output from the initial survey with the 11 factors shown in Figure 3. From the both owner and industry experts rated groundwater/water table issues as the most frequent geotechnical factor. It is notable that the three geotechnical factors (groundwater/water table, settlement, and contaminated material) from the Figure 7 survey are within the top 11 factors shown in Table 4. In addition, it should be noted that the Table 4 factors range from the 20% to 68% frequency occurrence, meaning that subsurface conditions and underground construction activities risks are broadly recognized as being one of the major areas of risk exposure in DB contracts to all parties (Dwyre 2012).

TABLE 4. Frequency of Geotechnical Factor Risk in DB Projects

FACTOR/RISK	Frequency Index [%]	Freq. Rank	11-Factor List Rank
Water table changes	67.56	1	2
Settlement in general	60.93	2	1
Settlement of bridge approaches	56.82	3	NA
Soft compressible soil	55.35	4	NA
Replace in situ material with borrowed material	54.76	5	NA
Presence of rock/boulders	54.42	6	NA
Scour of bridge piers	54.00	7	NA
Unsuitable material	53.02	8	NA
Contaminated material	51.43	9	4
Ground water infiltration	51.16	10	NA
Seismic Risk	50.73	11	NA
Highly compressive soils	49.33	12	NA
Existing structures likely to be impacted by the work (other than utilities)	48.84	13	NA
Slope instability	48.37	14	3
Soft clays, organic silts, or peat	48.26	15	2
Underground manmade debris	47.73	16	NA
Settlement of adjacent structure	46.36	17	NA
Sensitiveness of public consideration (Parks, historic building, etc.)	46.19	18	NA
Liquefaction	44.29	19	NA
Landslides	43.00	20	6
Lateral spreading	42.93	21	NA
Rock Faults/ Fragmentation	42.93	22	7
Eroding/mobile ground conditions	39.51	23	NA
Subsidence (subsurface voids)	39.07	24	5
Karst formations	38.60	25	9
Caverns/voids	37.62	26	NA
Chemically reactive ground	34.87	27	8

Impact Geotechnical factors

Table 5 shows the impact of geotechnical factors in DB project cost and schedule performance. It is striking that the top five are factors that are difficult or impossible to quantify prior to the execution of the project. These factors are:

1. contaminated material,
2. slope instability,

3. landslides,
4. settlement of adjacent structure, and
5. highly compressive soils.

Generally, these factors are encountered after the design-builder has commence construction on site. One can see that the results of the impact index calculation are generally higher that than the frequency index calculations. The impact indices range from the 51% up to 72%. The results are consistent with the findings of NCHRP Synthesis 429, (Gransberg and Loulakis 2012), affirming that geotechnical conditions not only have an enormous impact on DB projects, but also directly affect project cost and schedule.

TABLE 5. Impact of Geotechnical Factor Risk in DB Projects

FACTOR/RISK	Impact Index [%]	Impact Rank	11-Factor List Rank
Contaminated material	72.38	1	4
Slope instability	72.09	2	3
Landslides	71.50	3	6
Settlement of adjacent structure	68.64	4	NA
Highly compressive soils	68.44	5	NA
Subsidence (subsurface voids)	66.98	6	5
Soft clays, organic silts, or peat	66.52	7	2
Sensitiveness of public consideration (Parks, historic building, etc.)	65.71	8	NA
Scour of bridge piers	65.50	9	NA
Soft compressible soil	65.12	10	NA
Seismic Risk	63.90	11	NA
Existing structures likely to be impacted by the work (other than utilities)	63.72	12	NA
Water table changes	63.11	13	2
Lateral spreading	62.93	14	NA
Liquefaction	62.86	15	NA
Caverns/voids	62.38	16	NA
Karst formations	62.33	17	9
Settlement in general	61.86	18	1
Settlement of bridge approaches	61.36	19	NA
Rock Faults/ Fragmentation	60.98	20	7
Underground manmade debris	60.91	21	NA
Presence of rock/boulders	60.00	22	NA
Unsuitable material	58.60	23	NA
Chemically reactive ground	57.95	24	8
Eroding/mobile ground conditions	56.59	25	NA

Ground water infiltration	56.28	26	NA
Replace in situ material with borrowed material	51.43	27	NA

Ranking the Importance of Geotechnical factors

The importance index of each geotechnical risk factor is shown in Table 6 in descending order. It is noteworthy that the top two geotechnical factors importance index which are groundwater/water table and settlement in general, are the same two first in the frequency index suggesting that, basically, the majority if not all DB projects are exposed to these type of two risks. Researchers' intention by means of this paper is to recommend geotechnical factors that should be addressed and clarify during the preliminary geotechnical investigation of a DB project. Furthermore, it is interesting note that the first (groundwater/water table) factor based on importance index seems to be an outlier in regards to all factors corroborating the suggestion that groundwater is an inherent geotechnical factor in transportation projects.

TABLE 6. Importance Index of Geotechnical Factor Risk in DB Projects

FACTOR/RISK	Importance Index [%]	Rank
Groundwater/ Water table	42.64	1
Settlement in general	37.69	2
Contaminated material	37.22	3
Soft compressible soil	36.04	4
Scour of bridge piers	35.37	5
Slope instability	34.87	6
Settlement of bridge approaches	34.87	7
Highly compressive soils	33.77	8
Presence of rock/boulders	32.65	9
Seismic Risk	32.42	10
Soft clays, organic silts, or peat	32.10	11
Settlement of adjacent structure	31.82	12
Existing structures likely to be impacted by the work (other than utilities)	31.12	13
Unsuitable material	31.07	14
Landslides	30.75	15
Sensitiveness of public consideration (Parks, historic building, etc.)	30.35	16
Underground manmade debris	29.07	17
Ground water infiltration	28.79	18
Replace in situ material with borrowed material	28.16	19
Liquefaction	27.84	20

Lateral spreading	27.01	21
Rock Faults/ Fragmentation	26.17	22
Subsidence (subsurface voids)	26.17	23
Karst formations	24.06	24
Caverns/voids	23.47	25
Eroding/mobile ground conditions	22.36	26
Chemically reactive ground	20.21	27

Conclusions and Recommendations

This paper's objective was to prioritize geotechnical risk factors that should be addressed during the preliminary geotechnical studies and prior to the award of a contract. The research is limited to a DB projects. Twenty-seven DB geotechnical risk factors were identified by the analysis of the literature review, case studies, and expert geotechnical engineers. A survey of experts provide input data on perceived risk for each and they were then ranked based on DB geotechnical risk importance index. The research's primary finding is that geotechnical risk is not currently a critical factor of a DOT's DB project delivery selection decision. Therefore, it makes identifying and planning the management/mitigation of DB project geotechnical risks during RFP development a critical factor. The following are other conclusions reached as a result of the analysis:

- Water table and settlement issues are the most frequent, highest impact, and most important risks that should be addressed in a DB RFP.
- Contaminated materials and soft compressible soils rank number 3 and 4.
- Table 6 can be used as a checklist during DB project development to ensure that geotechnical risk is adequately address in the DB RFP.

This research seeks to add to the body of knowledge within the classification of geotechnical risk factors. The findings of this research will assist DOTs in prioritizing how much and what type of preliminary geotechnical studies are needed to characterize a project's underground conditions to be addressed in the RFP. Because geotechnical conditions are unique of each project, the research also helps DOTs gain a perspective on geotechnical risk's level of impact of that these can be used allocate risk between the owner and the successful design-builder during project execution. The study's findings are supported by the literature, case studies, expert opinions and online surveys.

CHAPTER 6. DESIGN-BUILD GEOTECHNICAL RISK SHARING AS A MITIGATION TOOL

Castro-Nova, I., Gad, G.M, Touran, A., Cetin, B., and Gransberg D.D., "Design-build Geotechnical Risk Sharing as a Mitigation Tool," *Journal of Management in Engineering*, ASCE (to be submitted).

Abstract

Managing geotechnical risk in Design-build (DB) projects is complicated due to the fact that the contract is awarded before a thorough subsurface investigation is conducted. The situation is make worse when the geotechnical content in request of proposal (RFP) is inadequate or ambiguous. State departments of transportation (DOT) are the maker the decision on how geotechnical risk is allocated between the owner and design-builder. This paper analyzes the difference in perceived DB geotechnical risk between DOT geotechnical engineers and members of the DB industry. Twenty-seven geotechnical risk factors were rated on a basis of frequency and impact by 46 DOT and industry practitioners and the results were analyzed using importance index theory. One finding was an inventory of critical geotechnical risk factors that would cause a DOT profession to recommend delivery of a project by a method other than DB, which is compared with risks that industry members indicated would cause them to not bid on a DB project. The study also found that there is a statistically significant difference in the perceptions of the importance of geotechnical risk factors between public agencies and industry and proposes alternatives to manage geotechnical risk.

Introduction

Research has shown that individual and organizational assessment of risk is fundamentally a function of perceptions. Additionally, "social scientists noted that perception of risk is unique to each person and is rooted in our values, education, experiences, and stake in the outcome" (Beecher et. al 2005). Classic risk perception theory maintains the magnitude of a given risk is a function of its potential impact and what is known in social science as "outrage factors," which essentially embodied the intensity of the observers' fear of the given risk's impact (termed the "hazard" in the social science literature). Fear of potential consequences is directly proportional to the level of uncertainty associated with the consequences' frequency of occurrence. The ability to quantify the uncertainty depends on how familiar the analyst is with the specific risk. Hence, an expert that is very familiar with a specific risk will perceive its potential impact in a differently than a knowledgeable non-expert (Beecher et. al 2005). In geotechnical engineering terms, an engineer with an advanced degree in seismic design will perceive a lower level of uncertainty regarding seismic risk factors than a geotechnical engineer with a bachelor's degree in civil engineering. As a result, it's important to account for differing perceptions of geotechnical risk during a DB project's procurement process.

Design-build (DB) projects delivery has proven to be one method to accelerate the construction by allowing construction begin before the design is fully complete (FHWA 2006). Similarly, DB delivery allows the state departments of transportation (DOT) to shift some of the responsibility for completing the necessary geotechnical investigations to support the geotechnical design to the design-builder after the award of the DB contract (Gransberg and Loulakis 2012). Therefore, DB delivery creates a substantial geotechnical risk profile that is skewed towards the design-builder because its lump sum bid is based on the uncompleted geotechnical design. DOTs have the ability to influence the level of geotechnical risk by the amount of preliminary geotechnical investigation they conduct and include in the request of proposals (RFP).

The DOTs' decision represents a significant impact beyond strictly risk allocation (Hatem 2011). Asgari et. al (2016) in its study found that the risk attitude has a significant impact on bidding performance of contractors and moderate risk averseness is the optimal policy. The design-builder's attitude is based on the geotechnical information included in RFP. DOTs' RFP package should provide proposing design-builders with enough subsurface information to allow them to generate a conceptual designs for structures that are dependent on the geotechnical conditions of the site. When the subsurface and geologic project information is inadequate, then the proposing design-builder has two options (Christensen and Meeker 2002). First, the design-builder can include a large contingency in the price to cover what its geotechnical designers would believe to be the worst possible scenario (Hartman and Snelgrove 1996). The second option is to declare the project as too risky and choose not to bid (Dwyre et al. 2010). Either election the DOTS are negatively impacted. In the first case, the contingency could drive the price outside the available budget and make it impossible to award. In the second case, the pool of qualified competitors becomes shallower, possibly leaving only one competitor that do not recognize the actual geotechnical scope risk. Thus, the DB contract might be exposed to a company that does not realize it is in trouble until the geotechnical risks are quantified during the design process, or also exposes a DOT to either a major differing site condition claim or a design-builder that has underpriced the job and is in financial concern.

Risk can affect productivity, quality, performance, and budget of a construction company, and the risk can be minimized or transferred between the parties (Kangari 1995). Hatem and Corkum (2014) in their study state that DOTs are resorting to DB delivery as a method to transfer subsurface condition risk to the private sector. The literature also demonstrate that as geotechnical uncertainty increases, the contingencies to cover those risks increase in design-builders' bids. As such, balancing subsurface condition risk allocation in the DOTs' RFPs has potential to not only decrease the project cost, but importantly increase cost and schedule certainty for the overall success of the DB project.

For the above reasons, it is critical that DOTs carefully consider the risk associated with the site's subsurface and geological conditions from the design-builders' perspective and translate that analysis into carefully crafted preliminary geotechnical investigation that can be used as the basis for allocating geotechnical risk in the DB project's solicitation. The evaluation should look at means to equitably share the risk to decrease the contractors' perceived uncertainty.

The purpose of this paper is to identify and report the differences between agency and industry perceptions of the impact of cogent geotechnical risk factors in DB projects. The paper will propose a set of recommended practices for managing geotechnical risk prior the award of the DB contract. The information is drawn from a comprehensive literature review supplemented by two DB practitioner surveys. One questionnaire sought to identify current DB geotechnical risk management practices, and the second quantified the difference in DOT and industry perceptions of geotechnical risk factors that are crucial in DB projects.

Background

Research has shown that managing geotechnical risk in DB projects might well be the most difficult aspect for alternative project delivery (Clark and Borst 2002; Schaefer and Berg 2011). When a DOT implements DB delivery to accelerate schedules (Smith 2008), the DB contract is typically awarded with a limited geotechnical scope definition because the preliminary geotechnical investigation included in the RFP do not completely describe actual subsurface conditions (Beard et. al 2001). This situation allocates much of the subsurface a risk to the design-builder companies, reflecting in size of the contingencies in their bids. Contingencies are the contractor's protection against the event of a risk occurrence (Hartman and Snelgrove 1996). When contractors perceive high geotechnical risk, they have two options. The first is to include a large contingency in the price to cover what its geotechnical designers believe to be the worst possible scenario, and the second is to decide not to bid because the project's risks are too high (Dwyre et al. 2010). Understanding the industries' perception of geotechnical risk factors in DB projects assists the agency in managing geotechnical risk, as well as promoting a rational approach to computing project contingencies to cover those geotechnical risk factors that make bids being increase.

While there has been some limited study comparing owner and contractor perception of risks in general on construction between there is none that specifically covers on geotechnical risk factors. Kangari (1995) is his study discussed the attitude of U.S. construction companies toward risk, and compare the results from its survey with the results from the American Society of Civil Engineers (ASCE) survey issued in 1979. Both surveys sought to identify the level of importance of construction risk and how they should be allocated. It should be noted that both surveys included "differing site conditions" factor. Similarly, Ahmed et. al (1999) studied the attitudes and perceptions of Hong Kong contractors and owners regarding the importance of construction risk, and how it should be allocated. These risks ranged from unforeseen site condition to acts of God. Results of that study state that unforeseen site conditions is perceived as highly important from both perspectives, but both owner and contractor respondents were undecided on the proper allocation of this risk. Other studies emphasizing on the allocation of risks have been made. Likhitruangsilp and Photios (2009) studied the risk allocation for tunneling contracts. The authors suggest that risk-sharing practices benefit owners by reducing the size of contingency sums included in the bid price to cover the risk of encountering adverse ground conditions. The study highlighted the International Tunnelling Association (ITA) recommendation that the risk of unforeseen and/or differing site conditions due to inadequate site investigation should be shared between the owner and the contractor.

A recent study that assessed DOTs' current practices for managing DB geotechnical risks in projects made a number of recommendations (Castro-Nova et. al 2016). First, the authors recommended that geotechnical uncertainty be reduced by DOTs providing all available subsurface information at the time the DB project is advertised to permit competing DB teams the best picture of project conditions as they make risk pricing decisions during the bidding. The study also found that the cost of geotechnical uncertainty at the time of bidding can be mitigated by the thoughtful sharing of project-specific geotechnical risks in the DB RFP.

Research Method

The study's methodology relied on two independent research instruments. The first instrument was a comprehensive review of literature in relation to the approach of sharing geotechnical risk in DB projects between DOTs and DB contractors. The literature review focused on the manner that DOTs allocate and manage geotechnical risk in their DB contracts prior the award of the contract, as well as the industry perspectives on the result bearing these risks.

The second instrument was composed of two surveys of agency and industry geotechnical personnel experienced in DB project delivery. The initial online-questionnaire identified current DOT policies and procedures for articulating geotechnical information in DB solicitations with a specific focus on determining current practices for allocating geotechnical risk. This survey was initially issued to the members of the American Association of State Highway and Transportation Officials (AASHTO) Subcommittees on Construction and Design in each of the DOTs. The subcommittee members were asked to then forward the survey to the person best-qualified to respond on an overall department basis. Responses were received from 38 DOTs yielding an overall response rate of 76%. Most of the respondents (80%) were assigned to the department's geotechnical/foundations section the remainder were DB project managers that administer the DB contract through project completion. Hence, the survey results reflect the perceptions of the most technically qualified group in each agency.

The second survey sought to measure the perceptional differences using DB geotechnical factors impact and frequency assessment to provide the necessary data to develop an objective ranking of those factors based on Importance Index theory (Assaf and Al Hejji 2006). The second survey was targeted at members of the AASHTO Subcommittee on Material's Technical Section 1b – Subsurface Exploration and a select group of industry practitioners with DB experience on projects with a high geotechnical content. A pilot questionnaire was sent to one DOT and one industry expert to test the understandability and clarity of the survey given the highly specific information sought in this survey. The pilot test resulted in important modifications to the questionnaire. The revised questionnaire was then deployed to the DOT and industry target populations. A total of 46 valid responses were received from 22 DOTs and 24 industry experts, yielding an overall response rate approximately 31%. The survey asked respondents to rate the frequency of 27 risk factors on DB transportation projects using a Likert scale ranging from never occurs (0) to occurs very often (4) for frequency of occurrence as well as impact on a Likert scale from no impact (0) to catastrophic impact (4). Table 7 contains the list of factors that were rated.

TABLE 7. DB Project Geotechnical Risk Factors

FACTORS/RISKS	
Groundwater/ Water table	Replace in situ material with borrowed material
Soft clays, organic silts, or peat	Ground water infiltration
Highly compressive soils	Caverns/voids
Rock Faults/ Fragmentation	Soft compressible soil
Chemically reactive ground	Underground manmade debris
Contaminated material	Settlement of adjacent structure
Slope instability	Sensitiveness of public consideration (Parks, historic building, etc.)
Seismic Risk	Eroding/mobile ground conditions
Lateral spreading	Existing structures likely to be impacted by the work (other than utilities)
Liquefaction	Presence of rock/boulders
Settlement in general	Unsuitable material
Settlement of bridge approaches	Karst formations
Subsidence (subsurface voids)	Scour of bridge piers
Landslides	

Analysis and Results

As detailed in the methodology, the analysis of the DB geotechnical factors assessment questionnaire sought to investigate the differences between DOTs and DB industry perceptions of 27 common geotechnical risk factors. Results were divided into two populations: DOTs personnel and industry practitioners. They were then analyzed using descriptive statistics and inferential statistics, and was the descriptive statistical analysis conducted in accordance with Importance Index methodology (Assaf and Al Hejji 2006; Santoso and Soeng 2016). This methodology requires the analyst to initially calculate a frequency index and an impact index based on the perceptions of the expert survey respondents. These are then combined mathematically to calculate an importance index for each factor. The underlying theory is that a risk with a high impact that frequently occurs is more important than a high impact risk that rarely occurs.

The approach proposed by Assaf and Al Hejji (2006) was adapted for use in the geotechnical risk context. The Importance Index, is a function of the Frequency Index (FI) and Impact Index (II). The indices are computed as shown in equations 1, 2, and 3 below:

Frequency Index: This formula was used to rank the geotechnical factors based on the frequency of occurrence as indicated by the contestants

$$Frequency\ Index\ (FI)(\%) = \sum a \left(\frac{n}{N}\right) * 100/5 \qquad \text{(Eq. 1)}$$

Where a = is a constant defining the weighting assigned to each response (ranges from 0 for Never up to 4 for Very Often), n = is the frequency of the responses, and N = is the total number of responses.

Impact Index: This formula was used to rank the geotechnical factors based on the impact of as indicated by the contestants

$$Impact\ Index\ (II)(\%) = \sum a \left(\frac{n}{N}\right) * 100/5 \qquad \text{(Eq. 2)}$$

Where a = is a constant defining the weighting assigned to each response (ranges from 0 for No Impact up to 4 for Catastrophic impact), n = is the frequency of the responses, and N = is the total number of responses.

With these two indices computed, the Importance Index can be calculated by the following formula:

$$Importance\ Index\ (IMPI)(\%) = [F.I.(\%) * I.I.(\%)]/100 \qquad \text{(Eq. 3)}$$

The indices explained above were applied to each of the 27 geotechnical risk factors shown in Table 7. The output from those calculations was then used to objectively rank geotechnical risk factors in DB projects.

Perceptions Geotechnical Risk Factor Impact

It is reasonable to expect that the perception of the impact index between DOTs and DB industry differ from each other. According to a study completed by Gransberg and Tapia (2016), contractual allocation of geotechnical risk in a construction project is always a challenge for owners. This challenge is to determine whether the competing DB contractors' view the impact of geotechnical risk factors is significantly different than the DOT's view. NCHRP (National Cooperative Highway Research Program) Synthesis 429, (Gransberg and Loulakis 2012), affirmed that DB delivery allows DOTs to shed the responsibility for completing the geotechnical investigation necessary to support the geotechnical design to the design-builder after the award of the DB contract. In this environment, it is logical to think that DB industry's behavior towards geotechnical risk factors impact is more cautious than DOTs. Figure 1 shows the results based on the impact index between DB industry and DOTs, and Table 8 presents each factor by its corresponding number.

Based on Figure 8, one can see there are similarities and differences with respect to geotechnical impact. It is interesting to note that from DB industry's perspective, overall geotechnical risk factors are in medium impact zone with a trend towards high impact, while DOTs' view point the majority of these factors are in low impact zone. Only replace in situ material with borrowed material and unsuitable material are common factors belonging to low impact zone, while contaminated material and landslides are, practically, the highest impact of geotechnical factors from only DB industry's perspective. Slope instability factor seems to be a concerning factor from both parties. It is striking that caverns/voids factor has an opposite point of view from DB industry and DOTs. From the DB Industry's side is almost high impact, while DOTs' side is the lowest impact factor.

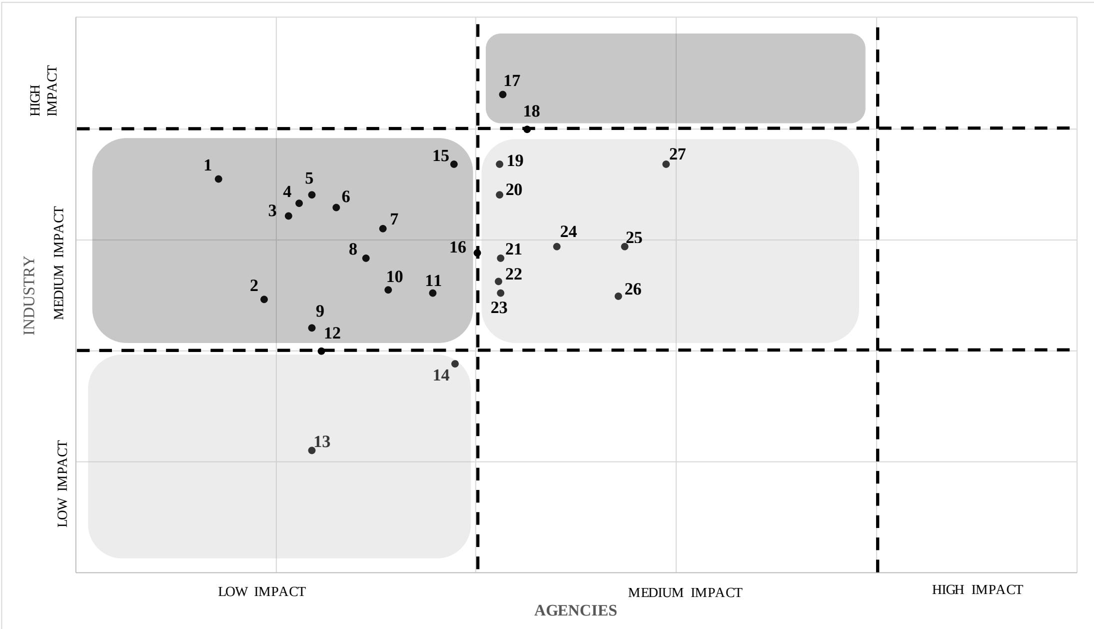


FIGURE 8. Perception of Geotechnical Risk Impact

TABLE 8. List of Geotechnical Risk Factors

Factor/Risk	Number	Factor/Risk	Number
Caverns/voids	1	Subsidence (subsurface voids)	15
Chemically reactive ground	2	Existing structures likely to be impacted by the work (other than utilities)	16
Liquefaction	3	Contaminated material	17
Karst formations	4	Landslides	18
Rock Faults/ Fragmentation	5	Settlement of adjacent structure	19
Lateral spreading	6	Sensitiveness of public consideration (Parks, historic building, etc.)	20
Seismic Risk	7	Soft compressible soil	21
Underground manmade debris	8	Groundwater/ Water table	22
Ground water infiltration	9	Settlement in general	23
Presence of rock/boulders	10	Soft clays, organic silts, or peat	24
Settlement of bridge approaches	11	Highly compressive soils	25
Eroding/mobile ground conditions	12	Scour of bridge piers	26
Replace in situ material with borrowed material	13	Slope instability	27
Unsuitable material	14		

Perception of Geotechnical Factor Frequency of Occurrence

Considering that DOTs and DB industries are both exposed to some degree of DB geotechnical risk, the difference in the frequency results, fairly similar between the two parties. Seismic risk, liquefaction, and lateral spreading are the highest had the widest perceived difference in perceived frequency. This difference is probably because most of the DOT respondents were located regions of the country where the likelihood of an earthquake is low. Whereas, most of the industry experts work is multi-state areas, which logically increases their exposure to the need to gauge seismic risk on their DB projects.

Perception of Importance of Geotechnical Factors

The computation of the Importance Index is shown in Figure 9. One can see that perceptions differ between the DB industry and DOTs. Industry perceptions attribute more importance to most geotechnical risk factors than the DOT perceptions. It is worth noting that there is nearly a 10-point difference between the most important geotechnical risk factors. It is noteworthy that although DB industry and DOTs differ on level of importance, both groups agree that these are the top risk factors are “groundwater/water table,” “settlement in general,” and “scour of bridge piers” of all the geotechnical risk factors. Similarly, “eroding/mobile ground condition” and “chemically reactive ground” are factors that have the lowest importance for both groups. The DOTs and industry only rated “replace in situ material with borrowed material” at the same level of importance. On the other hand, Figure 9 shows that “seismic risk” had the highest difference of perceived risk. As previously mentioned the difference is maybe due to the effect of the frequency index calculated for those agencies located in regions with low earthquake risk.

IMPORTANCE INDEX [%]	DOTs PERSPECTIVE	SIMILAR PERSPECTIVE	INDUSTRY PERSPECTIVE
47.00-51.00			Groundwater/ Water table
43.00-47.00			Seismic Risk Settlement in general Contaminated material
39.00-43.00			Scour of bridge piers Soft compressible soil Settlement of bridge approaches Settlement of adjacent structure Liquefaction
35.00-39.00	Groundwater/ Water table		Ground water infiltration Presence of rock/boulders Underground manmade debris Soft clays, organic silts, or peat Sensitiveness of public consideration Slope instability Landslides Lateral spreading Highly compressive soils Existing structures likely to be impacted by the work (other than utilities)
31.00-35.00	Settlement in general Soft compressible soil Slope instability Settlement of bridge approaches Scour of bridge piers		Rock Faults/ Fragmentation Subsidence (subsurface voids) Unsuitable material Karst formations Caverns/voids
27.00-31.00	Highly compressive soils Presence of rock/boulders Unsuitable material Sensitiveness of public consideration Soft clays, organic silts, or peat Existing structures likely to be impacted by the work (other than utilities) Contaminated material	Replace in situ material with borrowed material	
23.00-27.00	Landslides Underground manmade debris Settlement of adjacent structure Ground water infiltration		Eroding/mobile ground conditions Chemically reactive ground
19.00-23.00	Subsidence (subsurface voids) Rock Faults/ Fragmentation		
15.00-19.00	Eroding/mobile ground conditions Karst formations Seismic Risk Liquefaction Lateral spreading Chemically reactive ground Caverns/voids		

FIGURE 9. Importance Index of Geotechnical Risk Factors

Statistical Analysis of Risk Perception Differences.

A statistical analysis was further conducted using the pooled *t*-Test to if there is a statistically significant difference in the perception of the overall geotechnical risk factors between the two groups. The *t*-Test is a statistical technique that can be used as a test of independence (McDonald 2009). The independence test is used to determine whether two means are associated with one another (Runyon et. al 2009). The pooled *t*-Test is used when the variances from each group are assumed to be equal (De Veaux et. al 2008), and the Brown-Forsythe test was used verify that assumption for the study populations. Therefore, in this study, pooled *t*-Test of independence was used to determine whether there is a significant difference between the perception of DOTs and DB industry in evaluating the relative magnitude of the 27 geotechnical risk factors in DB projects. Because of the bias found in perceptions of the "seismic" risk factor due to locational impacts, it was dropped from the analysis to give more rigor to the study and provide a more generalizable result. Table 9 shows the two aspects tested. The hypotheses tested were the following:

H_{o1}: There is no statistical difference between DOTs and DB industry in their perception of geotechnical risk factors in DB projects.

H_{a1}: There is a statistical difference between DOTs and DB industry in their perception of geotechnical risk factors in DB projects.

H_{o2}: There is no statistical difference between DOTs and DB industry in their variances.

H_{a2e}: There is a statistical difference between DOTs and DB industry in their variances.

TABLE 9. Summary of Hypothesis Test Results for DOTs and DB Industry

Aspects tested	***t*-Test (*t*) / (*f*)**	**Significance (*p*)**
Perception of geotechnical risk factors in DB projects	6.616	0.000*
Variances	0.753	0.389*

As shown in Table 9, the following hypothesis tested were statistically significant: Perception of geotechnical risk factors in DB projects (*pooled t-Test = 6.616 and p-value = 0.0001*). The null hypothesis was rejected given that *p-value* < 0.05. Thus, there is statistically significant difference between how DOTs and DB industry perceive geotechnical risk factors in DB projects, with DB industry having more importance index on these factors. The variance aspect was tested and the hypothesis was accepted, with no statistically significant difference in their variances.

Geotechnical Risk Premium

The second purpose of the DB geotechnical factors assessment survey was to identify those factors identified as having “major” or “catastrophic” impact on DB projects that would cause a DOT expert to recommend foregoing DB delivery and an industry practitioner to choose not to bid on a DB project. A previous study (Castro-Nova et.al 2016) found that geotechnical risk is not currently a critical factor in a DOT’s DB project delivery selection decision. In other words, DOTs’ will use DB delivery regardless of the level of geotechnical risk. The same study proposed a prioritized list of geotechnical risk factors based on importance index to guide the preliminary investigations that characterize a project’s underground conditions to be addressed in the RFP. In this context, knowing those geotechnical risks that are perceived as critical by the DB industry allows the DOT to undertake specific investigations to increase the amount of subsurface information in those areas. This constitutes the pre-award mitigation of the procurement risk that a DB project cannot be awarded because the bids are too high due large contingencies for the project’s geotechnical risk (Gransberg and Loulakis 2012). Table 10 presents a comparison of perceived DOT and industry geotechnical factor risks. Table 4 leads one to conclude that the perceptions of critical geotechnical risks is not aligned. Thus, the potential that DOT contingencies will be inadequate is high as a result of differing perceptions. Christenson and Meeker (2002) would also argue that the pool of potential competitors will be made shallower due to the misalignment of perceived geotechnical risk.

TABLE 10. Geotechnical Risk Factors that Would Make Not to Pursue/Recommend a DB Project

Geotechnical Risk Factor	DTOs and DB Industry Agreement	DTOs and DB Industry Disagreement
Landslides	X	
Subsidence (Subsurface voids)	X	
Contaminated Material		X
Prediction of subsurface condition due to inaccessible drilling locations *		X
Sensitiveness of public consideration (Parks, historic building, etc.)		X
Karst formation		X
Slope instability		X

Geotechnical Risk Sharing Mitigation Identification

The initial survey conducted by researchers asked DOTs respondents how geotechnical risks are typically allocated in DB project RFPs. The ten most common geotechnical risks encountered in DB projects are shown in Table 11. The ten factors were then plotted against the differences in the importance index of the two groups found in Figure 9. Figure 10 illustrates the percentage of risk allocation versus the difference in importance index for the ten factors.

TABLE 11. Ten Most Encountered Geotechnical Risk Factors

Factor/Risk	Number	Factor/Risk	Number
Slope instability	1	Landslides	6
Soft clays, organic silts, or peat	2	Rock Faults/ Fragmentation	7
Chemically reactive ground	3	Settlement in general	8
Subsidence (subsurface voids)	4	Contaminated material	9
Groundwater/Water table	5	Karst formations	10

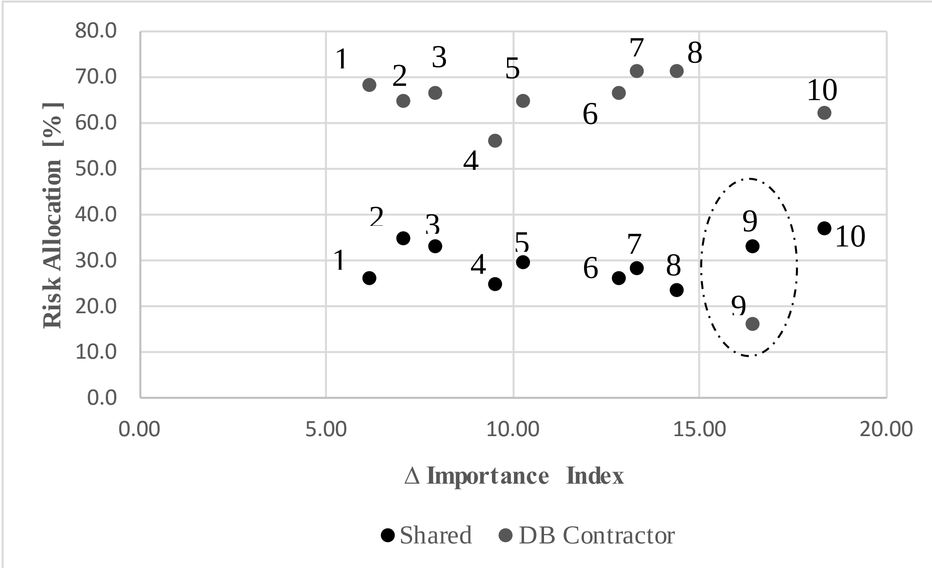


FIGURE 10. Geotechnical Risk Allocation in DB Contract

Figure 10 indicates that DOTs shed 9 of the 10 of the most important risks. Only "contaminated material" is shared by the DOTs. Settlement in general is the highest geotechnical risk factor that is allocated to the DB builder.

Figure 10 graphically illustrates an opportunity to mitigate geotechnical risk prior the award of DB contract. A high difference in importance index means that the DB industry perceives a particular risk to be more important to project success during the execution phase, and will reflect that perception in the size of the geotechnical contingency in their bid. If those risks are shared in some manner, the DOT can potentially benefit from reduced proposal contingencies, mitigating the risk that cannot be awarded in timely manner because all proposals are over budget.

Conclusions and Recommendation

The purpose of this paper is to propose an approach for identifying critical geotechnical risk in DB projects based on the perceptions of the project's stakeholders. It is hoped that once identified that the agency will use that information to mitigate it by providing a system to share key geotechnical risks in its DB solicitations. Based on literature review and surveys, the paper found and analyzed 27 geotechnical risks factors, using an importance index derived from DOT and DB industry perceptions of impact and frequency. The surveys serve as a benchmark against which specific project-level geotechnical risks can be measured. The surveys proved that DB industry is more conscious of the potential impact of geotechnical risks in DB projects than the agencies and that there is a statistically significant difference in the perceptions. Thus, the paper's main contribution is quantifying the difference in the perceptions which can then be used by DOTs to adjust early project budget and schedule expectations to better match the expectations of the DB industry that will ultimately execute the project.

The analysis discussed in this study resulted in the following specific conclusions:

- The perception of geotechnical risk factors between DOTs and industry differ in most of the 27 analyzed factors. Descriptive analysis shows that industry respondents tends to be more conservative in toothier perception of the relative importance of geotechnical risk factors than DOTs respondents.
- The research found similar perspectives on those geotechnical risk factors that DB delivery is not optimum a given project are:
    - Landslides
    - Subsidence (subsurface voids)
    - Contaminated material
    - Prediction of subsurface conditions due to inaccessible drilling locations
    - Sensitiveness of public considerations (Parks, historic building, etc.)
    - Karst formations
    - Slope instability

The study recommends that these factors should be addressed in the RFPs and suggests they should optimally be shared between DOTs and industry in order to decrease potential contingencies in proposals.

The results show that DOTs currently shed nine of the ten top geotechnical risks. Thus geotechnical risk sharing provides an opportunity to manage geotechnical uncertainties with an expected decrease in the amount of proposal price contingencies. The results support sharing geotechnical risk is a viable means manage geotechnical uncertainty during the procurement phase. Finally, the findings of this study can be used to mitigate geotechnical risk by focusing the conduct of specific underground preliminary investigations on the critical geotechnical risk factors.

CHAPTER 7. CONSOLIDATED CONCLUSIONS AND LIMITATIONS

This chapter consolidates the major findings from the three journal articles in Chapters 4, 5, and 6. One of the major issues confronting public agencies on any transportation project is the nature and predictability of geotechnical conditions. This issue is aggravated when DOTs use DB project delivery method to accelerate the execution. During the DB procurement stage geotechnical risk arises from two sources. One is related to the allocation of the geotechnical risk between DOTs and design-builders. This source embodies the amount of geotechnical information is included in the RFPs, and how geotechnical risks between DOTs and DB contractor are allocated. The second source is the uncertainty of the actual geotechnical conditions due to the fact that a DB contract is typically awarded with a limited geotechnical scope definition given that the preliminary geotechnical investigation included in the RFP, which may not completely describe actual subsurface.

The most consequential finding of the research is that large potential geotechnical risks do not stop DOTs from using DB delivery for a given project because the project delivery method decision is usually made before the amount of geotechnical risk is evaluated. However, geotechnical conditions not only have a huge impact on project design, but they directly impact project cost and schedule. The primary risk is that of project cost overruns due to differing site conditions that materially differ from what the design-builder should have reasonably expected when it priced its contract. Similarly, the project cost is increased based on design-builder's contingencies to cover not only the assumptions made in the preliminary geotechnical design, but also to cover the risk of encountering changed conditions.

The following list are the other conclusions reached during the thesis research:

- DOTs that are new to DB project delivery approach geotechnical risk differently than those that have completed more than 10 DB projects. The most difference was evidenced in the importance in the importance of the qualifications and past experience of the contractors' geotechnical staff. Additionally, experienced DOTs tend to share unknown geotechnical conditions while non-experienced DOTs share the risk or attempt to shed it. As it was mentioned in Chapter 4, one approach to manage geotechnical risk is to include as much geotechnical information as DOTs can during the procurement stage. This approach was noted on experienced DOTs meaning that they understand the importance of providing enough geotechnical information to reduce uncertainty during the bidding stage.

- There are 27 geotechnical risk factors based on geotechnical characteristics of a given DB project these should be considered and if applicable addressed in DB RFPs. Identifying and planning the management/mitigation of DB project geotechnical risks during RFP development is a critical factor, so knowing which are the most critical geotechnical factors that impact a DB projects determines the preliminary geotechnical studies that should be conducted prior the award of the contract. The thesis found that water table and settlement issues are the most frequent, highest impact, and most important risks that should be addressed in a DB RFP.

- There is a statistically significant difference in DOT and industry perception of the relative impact of the 27 geotechnical risk factors. The difference can potentially result in unexpectedly higher DB project costs or worse, a much shallower pool of qualified competitors. The thesis concludes that DB industry is more conscious of the potential impact of the geotechnical risk factors in DB projects than the DOTs. The perceptional difference also argues for NOT choosing DB project delivery before evaluating geotechnical risk.

- DB project delivery has not changed the DBB practice of attempting to shed geotechnical risk. Chapter 6 found that DOTs shed nine of the ten top geotechnical risk meaning. These risk are the following: geotechnical risk allocated to the contractor: slope instability, soft clays, organic silts, or peat, chemically reactive ground, subsidence (subsurface voids), groundwater/water table, landslides, rock Faults/ fragmentation, settlement in general, and karst formations; shared geotechnical risk: contaminated material.

- The thesis concluded that based on the similar perspective between DOTs and DB industry there seven geotechnical risk factors that makes a given project not be suitable for being DB delivery. The factors are: landslides, subsidence (subsurface voids), contaminated material, prediction of subsurface conditions due to inaccessible drilling locations, sensitiveness of public considerations (Parks, historic building, etc.), karst formations, and slope instability.

This thesis describes some tools to manage geotechnical risk in DB projects as well as the perception of DOTs and contractors with regard to this type of risk in DB highway construction projects. This practices are acceptable with the limitations of the knowledge available at the time of its development. The major limitation of this study was when survey participants were asked to rank factors. Because perception is based on experience, some results could be biased. In addition, there are a number of limitations during the preparation of this thesis. First, the gathered data from the DOTs surveys. Although the study used means such as reminders to collect all geotechnical information from those DOTs that currently practice DB delivery, DB information could not be collected from all the targeted population. Similarly, this situation occurred with the DB industry survey. Despite the fact that the survey had a representative data from the industry whose experience increased the accuracy of the results, it was almost impossible to have results from all DB companies' practitioners over the United States.

CHAPTER 8. CONTRIBUTIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This chapter summarizes the main contributions of each journal article presented in Chapters 4, 5, and 6. Additionally, it presents recommendations for future research to improve geotechnical management tools in DB projects as well as other aspects of geotechnical risk in this type of projects.

Contributions

The main contribution of this thesis is the development of multiple tools that were statistically tested, whose application is expected to enhance the management of geotechnical risk in DB projects. The main tools or practices are listed below:

- Giving appropriate emphasis to the qualifications and past experience of the design-builder's geotechnical staff during the procurement process facilitates management activities for the control and mitigation of geotechnical risk in DB projects.
- An effective practice for the management of the geotechnical risk in DB projects is to develop formal geotechnical risk analysis systems where geotechnical risk factors are identified, quantified and mitigated.
- Public agencies can manage geotechnical risk and decrease the uncertainty associated with DB projects by including in RFPs as much geotechnical information as possible. Thus, potential proposers are not forced to increase their geotechnical contingencies to compensate for the high levels of uncertainty.
- A reasonable sharing of risk between the owner and the design-builder helps to reduce the geotechnical risk perceived by the latter, reducing price proposals due to the inclusion of lower budget contingencies.
- Understanding the perception of the DB industry with regard to the impact of geotechnical risk factors during the execution of the project allows DOTs to identify potential issues that should be addressed during the preliminary geotechnical investigation in order to reduce their impact on project contingencies.

Recommendations for Future Research

Given the noteworthy increase in the use of DB delivery by state DOTs during the last couple of decades, further research on this area should be focused on improving the management tools proposed in this thesis and develop other effective practices for the management of the geotechnical risk in DB projects. The list below corresponds to specific recommendations for future research derived from this thesis:

- A benefit-cost analysis on the tools that were found during the development of this research.
- A further analysis of the variables that should be analyzed in geotechnical studies to optimize the effectiveness and maximize the utility of these studies.
- The development of practices that allow for an optimal distribution of geotechnical risk between owners and design-builders to guarantee the payment of reasonable cost contingencies.

REFERENCES

Ahmed, Syed M., Riaz Ahmad, D. E. Saram, and D. Darshi. "Risk management trends in the Hong Kong construction industry: a comparison of contractors and owners perceptions." Engineering construction and Architectural management 6, no. 3 (1999): 225-234.

Asgari, Sadegh, Amr Kandil, and Ibrahim Odeh. "Optimal Risk Attitude for Construction Contractors in Competitive Bidding Environments." In Construction Research Congress 2016, pp. 2474-2480.

Assaf, Sadi A., and Sadiq Al-Hejj. 2006. "Causes of delay in large construction projects." International journal of project management 349-357.

Baynes, F. J. "Sources of geotechnical risk." Quarterly Journal of Engineering Geology and Hydrogeology 43, no. 3 (2010): 321-331.

Beard, L.J., C.M. Loulakis, and C.E. Wundram. 2001. Design-Build: Planning Through Development. New York: McGraw–Hill Professional.

Beecher, N., Harrison, E., Goldstein, N., McDaniel, M., Field, P., & Susskind, L. (2005). Risk perception, risk communication, and stakeholder involvement for biosolids management and research. Journal of Environmental Quality, 34(1), 122-128.

Castro-Nova, Gransberg D.D, and Cetin B., Identification of Potential Geotechnical Risk Factors in Design-Build Transportation Projects. 2016

Castro-Nova, I., Gad, G.M., and Gransberg D.D., “An Assessment of State Agency Practices in Managing Geotechnical Risks,” Transportation Research Record, Journal of the Transportation Research Board, National Academies, Paper 17-03399, (Accepted for presentation and publication in January 2017).

Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications. Publication No. FHWA ED-88-053, August 1988, Revised February 2003. http://www.fhwa.dot.gov/engineering/geotech/pubs/reviewguide/checklist.pdf. October 10, 2016.

Christensen M.R. and Meeker, L.E. “Design/Build Projects – Lessons Learned from the Contractor’s Perspective,” Proceedings, American Railway Engineering and Maintenance-of-Way Association, Lanham, Maryland, 2002, p.14

Clark, G.T. and Borst A. “Addressing Risk in Seattle’s Underground,” PB Network, January 2002, pp. 34-38.

D., D. V. R., Velleman, P. F., & Bock, D. E. Stats: data and models. Boston: Pearson, 414 Addison-Wesley. 2008

Daoulas, J.C.. "Georisk in the design-build procurement process." In GeoRisk 2011, 2011.

DBIA, Design-Build Institute of America. 2010. State Statute Report. 10. Accessed 10 3, 2011. http://www.dbia.org/NR/rdonlyres/27DEBA31-342B-4177-B6E0 AE8D9108D518/0/StateStatuteRpt101029.pdf.

del Puerto, Carla Lopez, Douglas D. Gransberg, and Michael C. Loulakis. 2016. "Contractual Approaches to Address Geotechnical Uncertainty in Design-Build Public Transportation Projects." Journal of Legal Affairs and Dispute Resolution in Engineering and Construction 04516010.

Design-Build Institute of America. Design-build state laws for transportation procurement, 2013 [online] Available at: http://www.dbia.org/NR/rdonlyres/231CFB85-2483-4D8A87DF-BF72193C61D7/0/tran130103.pdf [February 2, 2013].

Drennon, P.W., “Utah’s I-15, a Transportation Case Study: Role of the Owner’s Design Professional in Design/Build and in the Provisions for Quality,” Quality Congress. ASQ’s ... Annual Quality Congress Proceedings, Milwaukee, Wis., 1998, p. 166

Dwyre, E.M., J.Jenkins, and R.J. Castelli. "Development and Interpretation of Geotechnical Contract Provisions for Design-Build Projects: Success Strategies for Owners and Contractors." In GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering, pp. 145-154. ASCE, 2012

Dwyre, E.M., Z. Batchko, and R.J. Castelli, “Geotechnical Baseline Reports for Foundation Projects,” Proceedings, GeoFlorida 2010: Advances in Analysis, Modeling & Design (GSP 199), Orlando, Fla., 2010, pp. 1–10.

Dwyre, Elizabeth M., Zoran Batchko, and Raymond J. Castell. 2010. "Geotechnical baseline reports for foundation projects." Proceedings GeoFlorida 2010: Advances in Analysis, Modeling & Design (GSP 199) 21-25.

Elizabeth M. Dwyre, John Jenkins, and Raymond J.Castelli. 2012. "Development and Interpretation of Geotechnical Contract Provisions for Design-Build Projects: Success Strategies for Owners and Contractors." InGeoCongress 2012: State of the Art and Practice in Geotechnical Engineering 2012. ASCE. 145-154.

Ernzen, Jim, and Tom Feeney. "Contractor-Led Quality Control and Quality Assurance Plus Design—Build: Who Is Watching the Quality?." Transportation Research Record: Journal of the Transportation Research Board 1813 (2002): 253-259.

Federal Highway Administration (FHWA), “SEP-14 Active Project List,” Washington, D.C. [Online]. Available: http://www.fhwa.dot.gov/programadmin/contracts/ sep14list.cfm [accessed Dec. 2, 2009].

Federal Highway Administration (FHWA), Design-Build Effectiveness Study—As Required by TEA-21 Section 1307(f): Final Report, FHWA, Washington, D.C., Jan. 2006, 215 pp. [Online]. Available: http://www.fhwa.dot. gov/reports/designbuild/designbuild0.htm [Mar. 20, 2011].

Federal Highway Administration (FHWA). 2009. Contract Administration. December 2. http://www.fhwa.dot.gov/programadmin/contracts/.

Federal Highway Administration (FHWA). Design-build effectiveness study – as required by TEA-21 Section 1307(f): final report, US Department of Transportation, Federal Highway Administration. Washington, DC.: Federal Highway Administration, 2006.

Gad, G.M, Gransberg, D.D. and M.C. Loulakis, “Submittal and Evaluation Procedures for Alternative Technical Concepts,” Transportation Research Record: Journal of the Transportation Research Board, No. 2504, Transportation Research Board of the National Academies, Washington, D.C., 2015, pp. 10-18

Gad, G.M., S.A. Adamtey, and D.D. Gransberg. "Trends in Quality Management Approaches to Design–Build Transportation Projects." Transportation Research Record: Journal of the Transportation Research Board 2504 (2015): 87-92.

GeoConstructability. An Owner’s Guide to Obtaining Essential Geotechnical Information for Construction Report of the Geotechnical Constructability Task Force Geo-Institute of ASCE August 2011. http://geotechnology.com/wp-content/uploads/2011/10/GeoConstructabilityReport201109.pdf. October 10, 2016.

Gransberg, D.D. and M.C. Loulakis. Geotechnical Information Practices in Design-build Projects. No. Project 20-05 (Topic 42-01). 2012.

Gransberg, D.D., K.R. Molenaar, and J.N. Datin, NCHRP Synthesis 376: Quality Assurance in Design-Build Projects, Transportation Research Board National Academies, Washington, D.C., 2008, 139 pp

Gransberg, Douglas D., and Michael C. Loulakis. 2012. Geotechnical Information Practices in Design-build Projects. No. Project 20-05 (Topic 42-01).

Gransberg, Douglas D., and Ricardo M. Tapia Pereira. "Alternative technical concepts: a geotechnical risk management tool." Journal of Structural Integrity and Maintenance 1.1 (2016): 43-49.

Gransberg, Douglas, and Ghada Gad. "Geotechnical Requirements in the Design-Build Selection Process." Transportation Research Record: Journal of the Transportation Research Board 2408 (2014): 26-33.

Harris, L.R. and Brown, G. “Mixing interview and questionnaire methods Practical Assessment.” Research & Evaluation, 15 (1) p. 2. 2010.

Hartman, Francis, and Patrick Snelgrove. "Risk allocation in lump-sum contracts-concept of latent dispute." Journal of construction engineering and management 122, no. 3 (1996): 291-296.

Hatem, D.J., “Risk Allocation for Subsurface Conditions and Defective Design,” Design-Build Subsurface Projects, G.S. Brierley, D.H. Corkum, and D.J. Hatem, Eds., Society for Mining, Metallurgy and Exploration, Englewood, Colo., 2011, 228 pp.

Hatem, David J., and David H. Corkum. "Purpose and Preparation of Geotechnical Baseline Reports in Design-Build and Public-Private Partnership Subsurface Projects." In Geo-Congress 2014 Technical Papers: Geo-characterization and Modeling for Sustainability, pp. 2314-2321. ASCE, 2014.

Ho, K., E. Leroi, and B. Roberds. "Quantitative risk assessment: application, myths and future direction." In ISRM International Symposium. International Society for Rock Mechanics, 2000.

Jaksa, M. B. 2000. "Geotechnical risk and inadequate site investigations: a case study." Australian Geomechanics 35.2: 39-46.

Kangari, Roozbeh. "Risk management perceptions and trends of US construction." Journal of Construction Engineering and Management 121, no. 4 (1995): 422-429.

Leahy, R.B., et al., Transportation Research Circular E-C137: Glossary of Highway Quality Assurance Terms, Transportation Research Board of the National Academies, Washington, D.C., May 2009, 44 pp.

Lee, M.C., Rueda-Benavides, J.A., and Gransberg, D.D. “Utility Management System Benefits and Barriers from the Local Agency Perspective,” Journal of Infrastructure Systems, ASCE, Vol 22, (1), 2016, pp.

Likhitruangsilp, Veerasak, and Photios G. Ioannou. "Risk allocation in standard forms of general conditions for tunneling contracts." In ASCE Proceedings of the Construction Research Congress, vol. 339, pp. 1250-1259. 2009.

Loulakis, M.C. and Shean, O. J., “Risk Transference in Design-Build Contracting,” Construction Briefings, 2nd series, Federal Publications, Washington, DC, 1996, 12pp

McDonald, J. H. Handbook of Biological Statistics, 2nd ed. Sparky House Publishing, Baltimore, Md., 2009.

McLain, K., D.D. Gransberg, and M.C. Loulakis. "Managing geotechnical risk on US design-build transport projects." Australasian Journal of Construction Economics and Building 14, no. 12 (2014): 1.

Mendez, V., “Every Day Counts: Innovation Initiative,” Federal Highway Administration, Washington, DC, 2010, p.1-2.

Molenaar, K., Vanegas, J., and Martinez, H. Appropriate Risk Allocation in Design-Build RFPs. Construction Congress VI (2000): pp. 1083-1092.

Oppenheim, A. N. (2000). Questionnaire Design, Interviewing and Attitude Measurement. Continuum, London.

Panchmatia, P., “Quality Through People: A Practical Approach,” American Society for Quality, 2010 [Online]. Available: http://www.asq-qm.org/pandp-qfd [accessed June 5, 2011].

Papernik, B.G. and Farkas, D.J., “Using Alternative Technical Concepts to Improve Design-Build and PPP Procurements,” Nossaman E-Alerts, (2005) [Online]. Available: http://www.nossaman.com/using-alternative-technical-concepts-improve-designbuild-ppp, [May 26, 2016].

Rueda-Benavides, J.A. and Gransberg, D.D., “Indefinite Delivery/Indefinite Quantity Contracting: A Case Study Analysis,” Transportation Research Record, No. 2408, Journal of the Transportation Research Board, National Academies, 2014, pp. 17-25.

Runyon, R. P., K. Coleman, and D. Pittenger. Fundamentals of Behavioral Statistics, 9th ed. McGraw-Hill, New York, 2002.

Santoso, Djoen San, and Sothy Soeng. 2016. "Analyzing Delays of Road Construction Projects in Cambodia: Causes and Effects." Journal of Management in Engineering p.05016020.

Schaefer, V.R., Douglas, S.C. and Berg, R.R., “SHRP2 R02 Geotechnical Solutions for Transportation Infrastructure: Guidance and Selection System,” TRB 2011 Annual 329 Meeting, Washington, D.C. January 2011

Smith, N.C., “Getting What You Paid For: The Quality Assurance and Acceptance Process for Transportation Projects,” Proceedings, American Bar Association Forum on the Construction Industry, Denver, Colo., 2001, pp. 17–18.

Smith, R. “An Evolving View of Geotechnical Engineering – A Focus on Geo-Risk Management Geotechnical Special Publication No. 178, GeoCongress 2008: Geosustainability And Geohazard Mitigation, New Orleans, Louisiana, March 9-12 2008, pp. 231-239

Songer, A. D., and K.R. Molenaar. "Selecting design-build: Public and private sector owner attitudes." Journal of Management in Engineering, 12.6, 1996: 47-53.

Touran, Ali, Douglas D. Gransberg, Keith R. Molenaar, and Kamran Ghavamifar. "Selection of project delivery method in transit: Drivers and objectives." Journal of Management in Engineering 27, no. 1 (2010): 21-27.

Tran, Dai Daniel, and Keith Molenaar. 2012. "Critical risk factors in project delivery method selection for highway projects." Construction Research Congress 2012.

Tran, Dai Q., and Keith R. Molenaar. 2013. "Impact of risk on design-build selection for highway design and construction projects." Journal of Management in Engineering 30.2: 153-162.

U.S. Army Corps of Engineers (USACE), Army Reserve Design/Build RFP Instruction Manual, USACE, Washington, D.C., Sep. 2009, 73 pp.

Varnes DJ Slope movement types and processes. In: Schuster RL, Krizek RJ (eds) Landslides, analysis and control, special report 176: Transportation research board, National Academy of Sciences, Washington, DC., (1978) pp. 11–33

Yin, Robert K. Case Study Research: Design and Methods. Sage Publications, New York, 2011.

APPENDIX A. GEOTECHNICAL STATE HIGHWAY AGENCY POLICIES AND PROCEDURES SURVEY

This appendix contains the online-survey used to collect the information from the analysis of current geotechnical management practices conducted in this research.

General Information:

1. US state in which the respondent is employed:
2. What type of organization are you employed by?
   - ☐ State Department of Transportation
   - ☐ Other public transportation agency; Name of Agency:
   - ☐ Federal Agency; Name of Agency:
   - ☐ Consultant; Name of Organization:
   - ☐ Contractor; Name of Company:
   - ☐ Other; Please describe:
3. What group/section do you work in?
   - ☐ Design group/section
   - ☐ Construction group/section
   - ☐ Operations group/section
   - ☐ Geotechnical/foundations group/section
   - ☐ Other, please specify:
   - ☐ Alternative project delivery group/section
   - ☐ Materials group/section
   - ☐ Contracts/procurement group/section
4. What project delivery methods is your organization allowed to use? Check all that apply
   - ☐ DBB
   - ☐ Construction Manager-at-Risk or Construction Manager/General Contractor
   - ☐ DB Best Value
   - ☐ DB Low Bid
   - ☐ Other; Please specify:

If your agency does not use Design-Build project delivery please skip to the 41question.

5. How many DB projects has your agency delivered?
   ☐ 1-2 ☐ 3-5 ☐ 6-10 ☐ >10

6. How long has your agency been using DB project delivery?
   ☐ 1-2 years ☐ 3-5 years ☐ 6-10 years ☐ >10 years

7. How many DB projects have you been personally involved in?
   ☐ 1-2 ☐ 3-5 ☐ 6-10 ☐ >10

Geotechnical Risk Management Information Section

8. Does your agency have a manual or document that specifically describes the procedures to be used with the geotechnical requirements of DB and/or DBB projects?
   ☐ No ☐ Yes. If yes, please add the web site URL address where it can be accessed or attach a corresponding document:

9. How much preliminary geotechnical investigation is completed before making the decision to use DB project delivery for a given project? *Check all that apply*
   ☐ None
   ☐ Reconnaissance Report (Review of records and observations from site)
   ☐ Geotechnical Data Report (Review of records and limited investigation data)
   ☐ Geotechnical Summary Report (Review of records and geotechnical investigation of critical areas)
   ☐ Preliminary Geotechnical Design Report (Partial geotechnical investigation)
   ☐ Geotechnical Design Report (Full subsurface investigation for all structures and geotechnical features)
   ☐ Geotechnical Baseline Report (GBR) (A report that establishes the contractual understanding of subsurface site conditions and upon which risks associated with subsurface conditions can be allocated between the owner and the design-builder)
   ☐ Geotechnical Interpretation Report (GIR) (A report that interprets the findings of the GBR)
   ☐ Other, please specify:

10. Do you use DB project delivery on projects where the geotechnical risks are considered to be significant, i.e. higher than the usual project?
    ☐ Yes ☐ No

11. If the answer to the question 10 is “Yes”, please check all applicable steps that were taken to address geotechnical issues in the DB RFQ/RFP?
    ☐ Geotechnical Baseline Report (GBR) (A report that establishes the contractual understanding of subsurface site conditions and upon which risks associated with subsurface conditions can be allocated between the owner and the design-builder)
    ☐ Allowance, restriction or elimination of Differing Site Conditions (DSC) rights
    ☐ Mandatory design
    ☐ Other, please specify:

12. (*Only for those who responded to the question 10 “YES”*) What are the Geotechnical characteristics or factors that preclude the project from being a DB contract delivery?
    ☐
    ☐
    ☐
    ☐

13. If the answer to the question 10 is “No”, Please check all the reasons why you do not use DB project delivery where the geotechnical risks are considered to be significant.

☐ Liability considerations (if so, specify:)
☐ Not willing to give up full control of the geotechnical design
☐ Inability to adequately describe geotechnical conditions and/or performance specifications
☐ Could use DB on these projects but political/policy issues prevent its use and/ or agency upper management is unwilling to use it
☐ Not enough time to conduct preliminary geotechnical engineering investigations
☐ Other, please specify:

14. Is a formal geotechnical risk analysis conducted on a typical project in any of the following areas? *Check all that apply*

Type of analysis / **Risk**	**Qualitative**	**Quantitative**	**Non-Formal Geotechnical Risk Analysis**
Project Scope	☐	☐	☐
Project Schedule	☐	☐	☐
Project Cost	☐	☐	☐
Contracting Risk	☐	☐	☐
Other, please specify:	☐	☐	☐

15. Within the geotechnical risk management process that is conducted by the agency or required of the design-builder, please select all that apply whether on a DB typical or a DB project with significant geotechnical issues:

(Check all that apply)	DB typical project	DB project with significant geotechnical risk
Geotechnical risk management process conducted by the agency prior to bid		
Formal risk identification meetings are conducted by the agency's project team prior to bid	☐	☐
Risk register, encompassing geotechnical risks, is developed by the agency	☐	☐
Risk mitigation report which includes procedures for mitigating risks identified during the risk analysis process is developed	☐	☐
Geotechnical risk management process required of the design-builder		
Design-builder has to develop a risk management plan to be submitted in the proposal to the agency	☐	☐

Design-builder has to maintain a risk register during the course of the project that includes the geotechnical risks anticipated and mitigation measures.	☐	☐

16. (*Only for those who marked to the question 15 "Risk Register and Risk management plan"*) Which of the following best describe the content of the risk register of geotechnical issues:

    ☐ Risk register developed by the agency determines the risk management mitigation strategies applicable to the geotechnical risks identified (such as share, transfer, and avoid)
    ☐ Risk register developed by the agency - encompassing geotechnical risks- is maintained during the course of the project (e.g. geotechnical risks that are not materialized are retired during the course of the project and contingencies are revised).
    ☐ Risk register developed contains geotechnical risks with a deterministic estimate of the cost and schedule impact of risk
    ☐ Risk register containing geotechnical risks and probabilistic estimate (range) of cost and schedule impact of risk
    ☐ Other, please specify:

17. Does your agency have a document that details your formal risk analysis/management process?
    ☐ No ☐ Yes. If yes, please add the web site URL address where it can be accessed or attach a corresponding document:

18. Does the geotechnical risk management process employed on DB projects differ based on the contract type (lump sum, unit price, etc.) ?
    ☐ No ☐ Yes

19. What types of geotechnical risks do you typically encounter on DB projects and how are they allocated? *Check all that apply*

Uncertainty in ground conditions	**Owner**	**DB Contractor**	**Shared**
Unknown geological condition	☐	☐	☐
Groundwater	☐	☐	☐
Soft clays, organic silts, or peat	☐	☐	☐
Rock Faults/ Fragmentation	☐	☐	☐
Chemically reactive ground	☐	☐	☐

Soil contamination	☐	☐	☐
Slope instability	☐	☐	☐
Settlement	☐	☐	☐
Subsidence (subsurface voids)	☐	☐	☐
Landslides	☐	☐	☐
Karst formations	☐	☐	☐
Others, please specify_____________	☐	☐	☐
Others, please specify_____________	☐	☐	☐
Uncertainty in the design process			
Inadequate geotechnical investigation	☐	☐	☐
Incorrect geotechnical design information, in general	☐	☐	☐
Bias and/or variation in design parameters being different than estimated, in general	☐	☐	☐
Inaccurate earthwork assumptions– soil or rock cuts or fills	☐	☐	☐
Risk in retaining structures assumptions and recommendations - geotechnical aspects	☐	☐	☐
Risk in structure foundations assumptions and recommendations (footings, driven piles, drilled shafts, etc...)	☐	☐	☐
Risk in ground improvement technique recommendations (wick drains, lightweight fill, vibro-compaction, dynamic compaction, stone columns, grouting, etc...)	☐	☐	☐
Risk in seismic design assumptions and recommendations	☐	☐	☐
Others, please specify_____________	☐	☐	☐
Others, please specify_____________	☐	☐	☐
Procurement/Contracts Risk			
Risk allocation in the differing site conditions (DSC) contract clause	☐	☐	☐
Others, please specify_____________	☐	☐	☐
Others, please specify_____________	☐	☐	☐

20. Do your project cost estimates involve a quantitative analysis of geotechnical uncertainty (i.e. was a range cost estimate developed)?
    ☐ Yes ☐ No ☐ Do not Know

21. If your answer to the question 20 is “Yes”, does it include a line item risk-based cost estimate of geotechnical risks
    ☐ Yes ☐ No ☐ Do not Know

22. Do you employ any formalized geotechnical risk allocation techniques to draft the **contract provisions**? (An example would be the decision to pay for piling or unsuitable material replacement by unit price rather than including it in the lump sum amount.)
☐ Yes, if yes, please describe: ☐ No

Geotechnical Aspects of Design-build Procurement Process

23. If geotechnical factors are included in the evaluation plan, how much weight do they carry with regard to all other evaluated factors?
☐ No weight ☐ minor weight ☐ some weight ☐ heavy weight

24. How much geotechnical information is provided in the DB Request for Proposals (RFP) in a *DB project with significant geotechnical issues*?
☐ None
☐ Reconnaissance Report (Review of records observations from site)
☐ Geotechnical Data Report (Review of records and limited investigation data)
☐ Geotechnical Summary Report (Review of records and geotechnical investigation of critical areas)
☐ Preliminary Geotechnical Design Report (Partial geotechnical investigation)
☐ Geotechnical Design Report (Full subsurface investigation for all structures and geotechnical features)
☐ Geotechnical baseline report (GBR)
☐ Other, please specify:

25. How much additional geotechnical information is required from the design-builders as part of their DB proposals in a *DB project with significant geotechnical issues*?
☐ None
☐ List of assumptions made regarding geotechnical conditions
☐ Limited additional testing as requested by the design-builders
☐ Pre-award geotechnical investigation of critical areas by design-builders
☐ Geotechnical design values to be used
☐ Preliminary designs for foundation features of work
☐ Proposed mitigation approaches for known or potential geotechnical risk areas
☐ Alternative technical concepts for geotechnical features of work
☐ Other, please specify:

26. During the bidding stage of a *DB project with significant geotechnical issues,* the agency: *(check all that apply)*
☐ Allows the proposers to do their own boring at the site
☐ Gives the bidders general site access and the results of the borings it had conducted.
☐ Allows alternative technical concepts (ATC) during the DB procurement process

27. Rate the following areas (if applicable) in terms of importance to the success of the project during the procurement process 1 = very important; 2 = important; 3 = not important; NA = Does not apply

Area	Rating

Sufficient geotechnical information to allow the competitors to price the project without excessive contingencies.	
Highly qualified geotechnical design engineers	
Formal geotechnical risk analysis conducted by agency	
Formalized geotechnical risk allocation techniques to draft the contract provisions	
Verification of knowledge and experience working in the project area	
Mandated use of agency design criteria	
Detailed GBR in RFP	
Geotechnical design QA plan in proposal	
Peer-review of GDR and supplemental GDRs	
Geotechnical construction QA plan in proposal	
Geotechnical risk mitigation plan in proposal	
Geotechnical ATCs with confidential one-on-one meetings	
Opportunity for competitors to conduct some form of subsurface investigation during proposal preparation.	
Correct weight of geotechnical issues in relation to other project requirements	

Geotechnical Aspects of Design-Build Contracts

28. What type of payment provisions are contained whether on a DB typical or a DB projects *with significant geotechnical issues*?

(*Check all that apply*)	DB typical project	DB project with significant geotechnical issue
Lump sum	☐	☐
Unit price GMP	☐	☐
Cost reimbursable	☐	☐
Lump sum guaranteed maximum price (GMP)	☐	☐
Unit price	☐	☐
Combination lump sum and unit prices	☐	☐
Other; Please specify	☐	☐

29. Please answer the following questions regarding geotechnical aspects of DB contracts:

	YES	NO	Do NOT Know
Does your agency use the GBR as a contract document?	☐	☐	☐
Do you provide and require geotechnical design criteria in DB contracts? If “Yes”: What type?	☐	☐	☐
Do you provide and require geotechnical performance criteria, such as maximum allowable settlement, in DB contracts? If “Yes”: What type?	☐	☐	☐
Do you use performance verification or measurement methods (instrumentation, etc.) for geotechnical features of work? If “Yes”: What type?	☐	☐	☐
Do you use warranties in conjunction with the geotechnical features? If “Yes”: What type?	☐	☐	☐
Do you have incentives that are used to align owner and contractor geotechnical risks and rewards? If “Yes”: What type?	☐	☐	☐

30. Does your DB contract contain a clause regarding geotechnical differing site conditions?
☐ Yes ☐ No

If your contract does not contain a clause regarding Geotechnical Differing site Conditions, please skip to the 35 question.

31. If the answer to the question 30 is “Yes”, how often does a design-builder’s claim of a differing geotechnical site condition result in a compensable change order?

☐ Never ☐ Occasionally ☐ Usually ☐ Always

32. Does your differing site conditions clause explicitly delineate the contractors' right to submit a claim for specific types of unforeseen conditions?
☐ Yes If yes: what types? ☐ No ☐ No Opinion

33. Please estimate the % of your DB projects that end up with a compensable differing site conditions change/claim:
☐ None ☐ 1-10% ☐ 11-25% ☐ 26-50% ☐ >50%

34. What document, if any, is used to define a differing geotechnical site condition?
☐ Geotechnical information contained in RFP
☐ GBR contained in RFP
☐ GDR produced by design-builder
☐ Contract differing site conditions clause definition only
☐ No document
☐ Other, please specify:

35. Has your agency had a major claim regarding a geotechnical issue on any of your DB projects?
☐ Yes. If yes, please describe the issue and the final decision:
☐ No

36. If the answer to the question 35 is "Yes", would you be willing to allow the research team to contact you to do a structured interview and collect case study information?
☐ Yes ☐ No

Please furnish contact information if different than respondent:

Contact name:
Phone number:
Email address

37. How do you rate the final quality of geotechnical work on DB projects compared to DBB projects?
☐ Better ☐ Same ☐ Worse ☐ No opinion
Please explain primary reason for difference:

38. Do you formally evaluate the design-builder's performance quality and use that for future DB selections?
☐ Yes ☐ No ☐ Do not know

39. Please rate the following geotechnical factors for their impact on the final quality/performance of the DB project.

Factor	Very High Impact	High Impact	Some Impact	Slight Impact	No Impact
Qualifications of the Design-Builder's geotechnical staff	☐	☐	☐	☐	☐
Design-Builder's past project experience with geotechnical issues	☐	☐	☐	☐	☐
Use of agency geotechnical specifications and/or design details	☐	☐	☐	☐	☐
Amount of geotechnical information expressed in the procurement documents	☐	☐	☐	☐	☐
Use of geotechnical performance criteria/specifications	☐	☐	☐	☐	☐
Early contractor involvement in geotechnical design	☐	☐	☐	☐	☐
Agency interactivity with geotechnical design team during proposal phase	☐	☐	☐	☐	☐
Agency interactivity with geotechnical design team during design phase	☐	☐	☐	☐	☐
Warranty provisions	☐	☐	☐	☐	☐
Confidential one-on-one meetings	☐	☐	☐	☐	☐
Geotechnical ATCs	☐	☐	☐	☐	☐

40. Do you have anything else you would like to share regarding the geotechnical aspects on your DB projects?

41. Only *for participant who skipped ahead from Question 4.* Please answer the following question based on the DB definition included in this survey, and your knowledge and/or experience related to DB contracting.

    If your agency would decide to implement DB contracting techniques; what would be your major concern in regard to the development of geotechnical requirements for the advertisement and letting of DB contracts?

APPENDIX B. GEOTECHNICAL RISK FACTORS IDENTIFICATION SURVEY

The purpose of this second questionnaire is to gauge the impact of geotechnical risk factors on Design-Build (DB) projects. The results of the survey is to identify those geotechnical factors that could preclude a given project from being DB project.

1. Please rate the following geotechnical risk factors with regard to their impact on a **Design-Build (DB) Project** in column A, as well as how often they typically occur in colur
In column C indicate those factors you rated as having either "**Major**" or " **Catastrophic**" Impact *which would make you NOT recommed DB delivery.*

Level of Impact Likert Scale			
0 =	No Impact	2 =	*Distinct or Some* Impact
1 =	Minor Impact	3 =	Major Impact
		4 =	Catastrophic Impact

Level of Frequency Likert Scale			
0 =	Never Occurs	2 =	Frequently
1 =	Occasionally	3 =	Often
		4 =	Very Often

	A					B					C
FACTOR/RISK	**Impact**					**Frequency of Occurrence**					**DB delivery not recommended**
	1	2	3	4	5	1	2	3	4	5	
Groundwater/ Water table											
Soft clays, organic silts, or peat											
Highly compressive soils											
Rock Faults/ Fragmentation											
Chemically reactive ground											
Contaminated material											
Slope instability											
Seismic Risk											
Lateral spreading											
Liquefaction											
Settlement in general											
Settlement of bridge approaches											
Subsidence (subsurface voids)											
Landslides											
Scour of bridge piers											
Karst formations											
Unsuitable material											
Presence of rock/boulders											
Utility conflicts											
Replace in situ material with borrowed material											
Ground water infiltration											
Caverns/voids											
Soft compressible soil											
Underground manmade debris											
Settlement of adjacent structure											
Sensitiveness of public consideration (Parks, historic building, etc)											
Eroding/mobile ground conditions											
Existing structures likely to be impacted by the work (other than utilities)											
Prediction of subsurface conditons due to inaccessible drilling locations											
Other:											
Other:											
Other:											

Do you have anything else you would like to share regarding the geotechnical risk factors on your DB projects?

APPENDIX C. INSTITUTIONAL REVIEW BOARD EXEMPTION DOCUMENT

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
1138 Pearson Hall
Ames, Iowa 50011-2207
515 294-4566
FAX 515 294-4267

Date: 10/1/2015

To: Dr. Douglas Gransberg
394 Town Engineering

From: Office for Responsible Research

Title: NCHRP Project 24-44 Guidelines for Managing Geotechnical Risks in Design-Build Projects

IRB ID: 15-502

Study Review Date: 9/29/2015

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

- (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  - Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  - Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**
- **You must carry out the research as described in the IRB application.** Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

  Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

  Detailed information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. **Only the IRB or designees may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

Please be aware that **approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies *requires* permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.**

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.