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Contractual Approaches to Address Geotechnical Uncertainty in Design-Build Public Transportation Projects

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CONTRACTUAL APPROACHES TO ADDRESS GEOTECHNICAL UNCERTAINTY IN DESIGN-BUILD PUBLIC TRANSPORTATION PROJECTS

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ABSTRACT

Geotechnical uncertainty may be the most difficult risk to manage in construction. In Design-Build (DB), where the project's price is fixed before design and in many cases the subsurface investigation is complete, the risk profile is fundamentally changed and the owner must address it. This paper assesses the potential of DB as a tool for addressing geotechnical uncertainty in public transportation projects by comparatively evaluating three successful approaches. The first case study involves the use of a Geotechnical Baseline Report as a subsurface condition risk allocation tool. The second uses unit price pay items inside the larger lump sum contract to share the geotechnical risk with the design-builder. Finally, a "nested DB" landslide repair clause inside a design-bid-build interstate highway contract successfully addressed the post-award potential landslide risk. The paper concludes that each of the contractual management approaches provided an effective means for addressing geotechnical uncertainty in DB public transportation projects.

KEYWORDS: Geotechnical, risk, design-build, contract formation, procurement.

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INTRODUCTION

A thorough geotechnical investigation is typically conducted as part of a transportation project's design process, and it is common practice to prepare a geotechnical design report (GDR) for use in designing subsurface project features such as foundations (WSDOT 2004). The tunneling industry takes the subsurface investigation and analysis to a more detailed level by developing a geotechnical baseline report (GBR) to act as a benchmark against which potential differing site conditions can be compared. It also permits a more equitable sharing of the risk associated with subsurface uncertainty with its contracting community, which is intended to reduce risk-associated contingencies in the bidding process (Dwyre et al. 2010). Regardless of the amount of sampling, testing and analysis that occurs prior to completing a project's design, the project's owner may still find itself liable for differing site conditions found after construction has commenced, making geotechnical risk management a difficult aspect for projects delivered using traditional design-bid-build (DBB) (Christensen and Meeker 2002). The geotechnical risk profile changes in design-build (DB) project delivery in a manner that potentially drives project success. A DBB project's design is finished before advertising the construction contract, but the design-builder completes both the design and the construction under a single contract in DB. As such, DB project delivery may involve the possibility that the subsurface geotechnical investigation will be undertaken by the DB contractor after executing a fixed price contract. That factor begs the question: how much investigation, if any, should the owner do prior to advertising the DB contract to characterize the geotechnical conditions upon which competing design-build teams will base their proposed price?

The highway construction industry is a somewhat late entrant into the use of DB project delivery. While public agencies have used it to some degree on vertical projects for at least four decades, it wasn't until the Utah Department of Transportation turned to DB as the only way to accelerate the highway construction required for the 2002 Winter Olympics that the industry saw it as a potential procurement tool (FHWA 2006). A major reason for not using DB until recently relates to the relative physical scales of building projects and highway projects. In building construction contracts, the probability that differing subsurface conditions will impact an architectural project is essentially limited to the building's footprint. However, a highway project's footprint is not only larger in area but also linear in shape, which greatly increases the probability that a differing site condition will be encountered. Add to that the fact that many public utilities are installed in the right of way of the nation's roads and the likelihood that the owner will be exposed to a serious differing site conditions claim greatly increases (Lee et al. 2015).

According to a study completed by FHWA, public transportation agencies tend to reserve DB delivery for projects that must conform to an accelerated schedule (FHWA 2006). This shortens the time available for both the owner and the successful DB team to conduct the subsurface investigations/analyses needed to quantify and mitigate the DB project's geotechnical risk. Additionally, the DB contractor is typically obligated to establish a firm fixed price during the bidding process before the design is complete and often before any new subsurface investigations have been undertaken. This forces the design-builder to include contingencies for the risk that the geotechnical design assumptions that were made during the bidding process turn out to be wrong. Those contingencies are paid by the owner whether or not they are actually realized due to the nature of a lump sum construction contract (McLain et al. 2014).

Additionally, the very physical nature of how a highway project is built adds fuel to the subsurface uncertainty fire because the subsurface construction activities are the first features of work that must be constructed, making them also the first technical features whose design must be completed (Gransberg and Gad 2014). This issue becomes especially acute when there is a need to release early design work packages for construction before the entire design has been finished. The result is an enormous pressure for the owner’s geotechnical engineers to truncate the traditional pre-award subsurface investigation, analysis, and design process to support the accelerated completion of the entire project.

An additional issue that the agency must also address is the contracting policy question of how much information should be provided to competing DB teams regarding the character of the geotechnical site conditions in the DB Request for Proposals (RFP) (Blanchard 2007, Dwyre et al. 2010). One school of thought maintains that the more information that is provided, the more likely it is that the design-builder can submit a competitive proposal because the contingencies for geotechnical risk contained in the price proposal can be reduced (Christensen and Meeker 2002). Additionally, this may provide the agency with enhanced certainty of expected project cost (Kim et al. 2009). Another school believes that increasing the amount of subsurface

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information merely increases the chance that it will be found different during construction, resulting in claims under the contract's differing site conditions clause (Rueda-Benavides and Gransberg 2015). However, because the DB delivery process has proven to be an effective means of compressing project delivery periods to their shortest states (FHWA 2006), there is frequently an incentive for the DOT to start the procurement process before a robust geotechnical program has been performed (Higbee 2004, Kim et al. 2009). All of this creates potential risks to both parties that are not present in a DBB delivery process (WSDOT 2004).

Therefore, managing geotechnical risk in DB projects is both important and timely. Given the high level of potential risk, there are public agencies that have sought and found contractual approaches to both manage and mitigate subsurface construction risk. As such, this paper will report how three public transportation agencies successfully leveraged the DB delivery process itself to address geotechnical uncertainty and resolve specific geotechnical issues.

METHODOLOGY

Case study research is best used to conduct an in-depth look at promising procurement processes such as DB (Eisenhardt 1991). Case studies help find the details of the "how and why" aspects for the project of interest. This is especially true for studies that examine a number of different cases (Yin 2008). The research team developed a defensible, repeatable methodology to direct the case study process. A variety of research methods were used, including multiple sources of information, maintaining a chain of evidence, and searching for patterns among the data through data coding (Taylor et al. 2009, Yin 2008). In-depth case study research was essential in this study to obtain the details of how different public agencies used DB project delivery as a risk management tool to address geotechnical uncertainty.

The research team developed a structured interview protocol with yes/no questions, checklists, matrices, and open-ended questions. The structured interview protocol facilitated understanding the uniqueness of each case study while having a standard output with which to analyze and conduct cross-case comparisons. Case study project candidates were identified from the literature, and each agency was contacted to identify a knowledgeable individual involved in the project with whom an interview could be arranged. The interview questionnaire was emailed to each interviewee one week before the scheduled interview to permit them time to gather the necessary information and documents for the case study. A copy of each DB project's RFP was requested that included all the applicable the geotechnical design criteria, soil profile information, test reports, etc. that would comprise the information upon which competing design-builders would have to base their proposals.

The researchers interviewed the agency's project manager for the Missouri and Montana projects and the DB contractor's project director on the Hawaiian project. The interviews were conducted in person with one researcher acting as the interviewer with a second researcher taking notes. The DB solicitation documents were also reviewed during the interview to ensure that their meaning was fully understood by the research team. After the structured interviews, each agency was furnished a copy of the draft case study reports and asked to verify the accuracy of the information contained in it. The case study details provided in the paper flow directly from the case study structured interviews and are supplemented by additional specifics found about the individual projects from the project documentation and elsewhere in the literature.

Case Study Selection and Demographics

Three case studies were selected for inclusion in this paper to highlight specific geotechnical issues that were addressed by using DB project delivery. It should be noted that they are a portion of a larger study which included a total of seven projects (Gransberg and Loulakis 2011). The case studies represent a cross section of variations in geotechnical uncertainty. The approaches may be generalized to other contracts or circumstances to address geotechnical uncertainty. The following ranges were considered when selecting the case studies found in this paper:

- Range of project types – roads and bridges
- Range of project size – small project to large
- Range of project location – regionally dispersed
- Range of solicitation type – Invitation for Bids (IFB) to Request for Qualifications (RFQ)/RFP
- Range of payment provisions – lump sum (LS) to time and materials
- Range of project cost - $0.55 million to $483 million

The three cases shown in Table 1 were specifically selected because the agency used DB as a contractual tool to address geotechnical risk, whereas the other four cases in the larger study merely reported the outcomes when differing site conditions were encountered. In others words,

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the three selected cases represent an agency that recognized the geotechnical risk potential in each project and then selected a carefully crafted tool to manage the risk using DB project delivery, presenting a proactive rather than reactive solution. The Table 1 is a summary of the salient characteristics of three case study projects analyzed in the paper.

TABLE 1. Case Study Project Summary

Agency	**Case Study Project (Value)**	**Project Type (location)**	**Geotechnical Risk Management/Mitigation Tool**	**Payment Provision Type**
City & County of Honolulu	Section I - West Oahu/Farmington Highway ($483 million)	Elevated Commuter Rail Guideway (Honolulu, Hawaii)	Use of GBR as DB contract risk allocation mechanism to mitigate potential contingencies for geotechnical uncertainty during procurement.	Lump Sum
Montana DOT	US Highway 2 Rockfall Mitigation ($3.0 million)	Rockfall mitigation features (Flathead County, Montana)	Use of a unit price provision to mitigate risk of geotechnical risks that could not be quantified until construction start.	Lump Sum with Unit Price items
Missouri DOT	I-270 – St. Louis County Slide Repair ($0.55 million)	Emergency landslide remediation on interstate highway (St Louis County, Missouri)	Use of a “nested” DB contract provision in a DBB contract with known geotechnical issues to respond to a major geotechnical risk if it is realized.	Time & Materials

CASE STUDY DETAILS AND ANALYSIS

The objective of this section is to portray the breadth and depth of the case study project population and analyze how DB project delivery was an effective means to provide geotechnical solutions and manage risk for transportation agencies. The format has been standardized for each project to enable each project to be compared with all other projects in the sample (Taylor et al. 2009).

West O'ahu/Farrington Highway Guideway Project, Section I—City and County of Honolulu, Hawaii (CCH)

This project involved the construction of 6.5 miles of elevated rail guideway resting on columns/ piers spaced at roughly 150 ft. This yields approximately 220 column/pier structures that support the elevated guideway. Salient elements of this case study are as follows:

- Geotechnical Scope: The project included about 220 separate foundations in conditions that included old and recent alluvium, localized areas of coralline deposits, isolated boulders and boulder fields, residual soils, and basalt bedrock. The owner anticipated that drilled shafts would be proposed for the majority of the alignment because they are usually less expensive and equipment and materials are usually readily available. (CCH 2008).
- Rationale for selecting DB project delivery: CCH chose DB project delivery because it wanted to award quickly to capture a drop in construction costs (Petrello 2009) and to allow design optimization by DB Team (Dwyre et al. 2010).
- Procurement: The project used a typical two-step process, with CCH first issuing an RFQ from which it developed a short list. It then issued an RFP to the members of the short list. The major technical issue that had to be resolved in the development of the RFP was to equitably allocate the risk of differing subsurface conditions. The owner settled on the use of a GBR to mitigate the significant risk of delay and/or cost escalation (Dwyre et al. 2010). The owner's geotechnical consultant chose to establish the baselines for each soil type. This was developed using preliminary geotechnical data obtained from a boring

program with a spacing of roughly one boring every 1,000 ft. Because the design-builder had authority to vary the alignment, this particular data set could easily be off the final alignment. Table 2 provides a summary of the GBR used to quantify the subsurface material properties risk.

Table 2: Geotechnical Baseline Report Baselines (adapted from Dwyer et al 2010)

Parameter	**Stratigraphy Baselines**	**Material Property Baselines**
Coralline	Undistributed quantity, not shown on subsurface profile	• % -#200 • %stratum depth cemented • Unconfined strength range
Recent Alluvium	Subsurface profile	• USCS types • Average shear strength by station reach
Older Alluvium	Subsurface profile	• USCS types • Average shear strength by station reach
Cobbles and Boulders	Lengths of foundation in cobble/boulder zone	• Thickness ranges of clinker and void zones
Clinker and Voids	Percent of foundations where clinker/voids will be present	• Thickness ranges of clinker and void zones
Rock	Subsurface profile line, with upper/lower bounds for planning construction means and methods	• Minimum RQD for specified percentage of core run • UCS
Groundwater elevations	Varying groundwater conditions shown on profile	• Water table or confined aquifer
USCS = Unified Soil Classification System; UCS=Unconfined compressive strength; RQD = Rock Quality Designation		

- <u>Quality Management (QM):</u> The agency’s general engineering consultant was responsible for most of the day-to-day QM tasks. The project also required considerable interaction between the design-builder and the agency’s consultant. Note that the two-dimensional Refraction Microtremor (2D ReMi) method was successfully used to map soft soil zones under the Farrington and the Kamehameha Highways, both of which support high traffic volumes, without the need to interrupt traffic flow (Sirles and Batchko 2010). This is example of innovation that was brought to the project by the use of DB project delivery.

- Summary: The project's award price was 15% less than expected indicating that the use of the GBR as a means to allocate risk was successful. Multiyear DB projects of this magnitude with significant geotechnical risks typically carry large contingencies inside the price proposal (Finley 2010). The CCH actually saved $87 million. Although it is impossible to know what percentage of the savings is due to lower construction prices, at least some of it must be assigned to a lower design-builder's contingency owing to the well-defined geotechnical risk.

US 2 Rockfall Mitigation Project - Flathead County, Montana DOT (MDT)

This project involved the design and construction of rockfall mitigation measures and slope stabilization along 14 miles of US Highway 2 east of West Glacier, Montana. Traffic control is a major issue on this job because the road provides access to Glacier National Park. Salient elements of this case study are as follows:

- Geotechnical scope: The project identified six reaches that must be mitigated and two more to be fixed if the contract funding is available. The project includes scaling, draped rockfall protection, trim blasting, and other techniques as may be determined by the design-builder.
- Rationale for selecting DB project delivery: MDT chose DB project delivery because it appeared to be the best method for sharing the risk of geotechnical uncertainty. The preferred rockfall mitigation method was to scale the rock faces back to a safe angle of repose. However, there is no economical method for determining the angle by any other method than field trial. As a result, completing the design before executing the construction contract carried an unacceptable risk because of the high potential for differing site

conditions changes/claims. The project had a fixed budget of $3.0 million with no contingency. MDT originally looked at using a fixed-price best-proposal best-value (BV) award algorithm (Gransberg and Molenaar 2003). However, MDT's enabling legislation requires it to use an adjusted score award algorithm, which requires the price be divided by the technical score with the lowest adjusted score becoming the BV (MDT 2011). The final alternative was to develop a unit price approach to those pay items that were expected to vary in quantities due to in situ geotechnical conditions and bundle the remaining items into a single lump sum price.

- <u>Procurement:</u> The partial unit price method allowed the technical proposal to be scored and did not constrain the competitors to a stipulated price. The RFP included a clause that made it clear that MDT intended to spend the entire budget for this project and get as much work done as possible. A "Best and Final Offer" clause provided a remedy if all initial price proposals exceeded the budget. In essence each responsive competitor would submit a revised proposal that details the scope of work it could complete for the specified budget. MDT would then repeat technical scoring and compute the BV based on the adjusted score. The RFP also explicitly encouraged including alternative technical concepts (ATCs) in the proposal and made it clear that innovation is encouraged in "means and methods, approach to the project, rockfall mitigation techniques, use of new products and new uses for established products." (MDT2011). The project's RFP used the following verbiage to explain how the unit price pay items for the rockfall mitigation work related to the lump sum bid price for the overall design and construction tasks, and Figure 1 is an extract of the project's bid price proposal.

> "The Bid Price Proposal form will include unit prices for the items indicated, a lump sum price for the remainder of the project scope and the completion date proposed by the Firm. …Each unit price will be multiplied by the quantity provided by MDT to determine the total amount for each of the unit price items. The Total Lump Sum for the project will be calculated by adding the extended sum of the unit price items with the lump sum amount for the remainder of the project scope. This total lump sum will be the final." (MDT 2011)

Figure 1 Design-Build Bid Price Proposal Form with Unit Price Items. (MDT 2011)

- <u>Quality Management:</u> MDT stayed actively involved in the QM process and shared many of the design and construction quality assurance tasks with the design-builder. This makes sense owing to the need to maximize the amount of work completed for the fixed budget. Joint responsibility also supports the issue that the final design is functionally reliant on trial and error data obtained in the field during actual scaling operations. It also supports the potential decision to reduce the number of reaches mitigated if the quantities overrun on early reaches by ensuring that the agency is actively engaged in verifying the actual angles of repose for the types of rock faces encountered in the field.
- <u>Summary:</u> MDT's procurement approach on this project illustrates an alternative for sharing the risk of geotechnical uncertainty on a DB project. "Unit price contracts are used for work where it is not possible to calculate the exact quantity of materials that will be required" (Schexnayder and Mayo 2006). In a lump sum contract, the design-builder bears the entire quantity risk. Unit pricing for specific features of work inside a lump sum DB

contract allows the agency to share the risk of the final quantities of work with the contractor and reduce the price. Requiring a lump sum price in a DB contract forces the contractor to bid the worst possible case for those items whose quantities cannot be accurately measured during proposal preparation (Gransberg and Reimer 2009). Thus, it makes sense to use the DB contract payment provisions to address geotechnical uncertainty through unit pricing.

I-270 Slide Repair Project, St. Louis County—Missouri DOT

This project involved the design and construction of temporary shoring needed to protect the interstate traffic as well to allow quick repair of the box culvert after a landslide. Salient elements of this case study are as follows:

- <u>Geotechnical scope:</u> Temporary shoring was used to allow the slope to be restored with shot rock. The project ultimately designed and built a temporary soil nail wall that had more than 150, 40-ft nails. The design-builder originated this innovative solution to replace MoDOT’s conventional slide plane removal and replacement technique (McLain 2008).
- <u>Rationale for selecting DB project delivery:</u> MoDOT awarded a DBB project on a conventional project in this location that contained a “nested” DB provision for repair of slides during construction by a prequalified geotechnical specialty subcontractor as required during the contract period. The primary rationale for selecting this form of DB was to reduce the time the roadway is out of commission and to encourage innovative methods to decrease the cost of the slope repair projects.
- <u>Procurement:</u> The typical MoDOT process to award a low-bid project includes a 10- to 14-week design review period before a construction contract can be advertised if the project

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costs more than $1.0 million. Added to this is another 3-week period to award the construction contract. By adding the "nested DB provision" for landslide repairs inside the DBB contract, MoDOT avoided the delays inherent in developing a new contract or the issues of getting waivers to react to an emergency requirement. The nested DB provision required the prime contractor to subcontract this work with a prequalified geotechnical specialty contractor that had previous experience successfully completing MoDOT slide repair and other types of projects.

- <u>Quality Management:</u> Because his DB project was constructed inside a larger DBB contract, one would expect MoDOT to approach QA in the same manner that it uses for DBB projects. However, it gave the design-builder the responsibility for QC testing in the same manner as its DB contract procedures.
- <u>Summary:</u> The project was completed 120 days after the slide damage occurred. The design took 5 days. These periods compare to an average of 205 days from slide to construction completion and 50 days for design for two similar projects that were procured using DBB (McLain and Shane 2009). The use of the soil nail wall permitted the construction to be completed without closing any lanes on I-270. In a conventional slide plane removal and replacement method, MoDOT would have needed to close at least one lane of traffic throughout construction. Figure 2 shows the damage done by the slide.

Figure 2 Interstate Highway 270 landslide damage. (McLain 2008).

Analysis of Case Studies

The three cases presented in the previous section represent successful approaches for leveraging DB project delivery to both mitigate and manage geotechnical risk. This runs counter to the conventional wisdom expressed in the literature that DB project delivery should be avoided on projects with high geotechnical uncertainty (Christensen and Meeker 2002, Hoek and Palmieri 1998, Scheepbouwer and Humphries 2011). For example, Blanchard (2007) described the Florida DOT's view that projects ""with low risk of unforeseen conditions… [and] low possibility for significant change during all phases of work" are good candidates for DB project delivery. Florida DOT also picks projects "that demand an expedited schedule and can be completed earlier," making the issue of unforeseen geotechnical conditions even more important.

Both the Montana and Missouri projects provided examples of how to embed risk mitigation tools inside the DB contract itself. MDT's use of selected unit pricing permitted it to share the quantity of work risk with the DB contractor and more interestingly, to provide a payment scheme where the total risk was capped by the $3 million contract ceiling. The idea here was to use every dollar of available to funding to get as much work done as possible by exploiting the contractual mechanisms for over and underruns in actual quantities. Thus, if actual quantities of scaling exceeded the estimated because the actual angle of repose of the scaled surface was less than estimated, MDT would stop the contractor when the total cost hit the budget ceiling. On the other hand if those quantities were less, then MDT could have the contractor continue on the project until it hit the maximum cost. MoDOT's "nested DB clause" inside a DBB project provided it a means to expeditiously repair a landslide if one occurred and when it did, the process was completed in 120 days, nearly three months faster that two previous landslides without the nested clause (McLain 2008). Both MoDOT and MDT anticipated the potential geotechnical risks and provided contractual mechanisms and remedies to mitigate their impact when they were realized.

The Honolulu project also anticipated the potential for differing site conditions claims, but instead of adding post-award contractual approaches to address it like the previous two cases, it chose to invest in a more thorough subsurface investigation that resulted in a GBR, which was included in the DB RFP. It also allowed the DB contractor to vary the alignment within the project limits based on post-award investigations that would be made by the successful DB team. The result was a rare amount of detailed information coupled with the explicit authority to deviate from the planned alignment to avoid subsurface conditions that might threaten the integrity of the contractor's proposed lump sum price. The fact that the project was awarded at a level of 15% below the engineer's estimate is testimony to the success of this contractual approach to managing geotechnical risk during the pre-award phase of DB procurement.

Not all DB projects have had such a prescient group of agency project delivery teams. The University Link Light Rail Project (U-Link) in Seattle, Washington provides an interesting contrast to the Honolulu transit project. This project however primarily consisted of a tunnel under Seattle's Portage Bay. An extensive risk management workshop was conducted during the preparation of the project's DB RFP, which resulted in the preparation of an interpretive GBR. The GBR was incorporated in the RFP, and the agency asked competing design-builders to provide "suggestions about equitable ways to share [geotechnical] uncertainty" (Clark and Borst 2002). One issue that arose during the outreach was a need for clarifying the "working definition of what material deviations from the GBR would constitute a differing site condition, upon which claims by the contractor would be addressed" (Clark and Borst 2002). After gaining a better understanding of how industry viewed the geotechnical risk profile, the owner settled on an approach that required each proposer to address in its proposal a series of "risk statements" by detailing its plan for addressing each specific risk via its preferred means and methods. The result was an unexpectedly large amount of effort that had to be invested in reviewing and evaluating the risk statement responses and as the evaluation panel looked at the risk statements, "more risks were recognized" (Clark and Borst 2002). In the end, the DB contract was terminated in 2001 and a decision was made to repackage and re-bid it.

The U-Link project is an example of an agency that recognized the need for geotechnical risk management, but in spite of making a valiant effort to develop a mechanism to share it, was unable to create an approach that filled the need and in the final analysis, one must infer that the project was not a good candidate for DB project delivery. This inference is borne out by the fact that portions of the project was eventually completed in 2013 using General Contractor/ Construction Manager (GC/CM) (Sound 2015). GC/CM (also known as CMGC or CM-at-Risk) a project delivery method where the contractor participates in the preconstruction design and planning but is not responsible for the completion of the final design. Additionally, the final construction cost is negotiated rather that competitively bid, which allows the agency to literally negotiate the risk allocation with the contractor before fixing the price (West et al. 2012).

SUMMARY AND RECOMMENDATIONS

Two primary conclusions are supported by the case study analysis and the approaches may be generalized to other contracts or circumstances. First, the decision to use DB project delivery for a project with greater than normal geotechnical uncertainty, like the Honolulu Guideway, cannot be made arbitrarily. The accelerated nature of DB not only shifts the geotechnical design responsibility to the DB contractor but it also greatly heightens the pressure to complete the geotechnical investigation and design tasks as quickly as practical to permit the start of early construction activities. The second conclusion is that DB project delivery can actually be used as a tool to mitigate the risk and facilitate the speedy resolution of geotechnical issues as was shown in the Missouri landslide.

The rest of the conclusions are project specific conclusions, highlighting how DB project delivery was used to resolve specific geotechnical challenges and general conclusions that focus on the effectiveness of using DB project delivery as a means to resolve geotechnical issues.

The following project specific conclusions can be drawn from the case study analyses:

- Investing the resources to prepare a GBR for a projects with a known high level of geotechnical variation provides a means to not only reduce the contingencies that must be included in a DB procurement but also provides an effective means to quantify differing site conditions if they are encountered.
- The use of selective unit pricing provides an effective means for managing geotechnical quantity risk.
- The use of a "nested" DB provision that requires a prequalified geotechnical specialty subcontractor to be a member of the team on a project with known geotechnical issues

provides an innovative solution to reduce response time to geotechnical issues unexpectedly arising during DBB project execution.

- O'ahu Elevated Guideway Project: The use of a GBR as a means to allocate subsurface condition risk appeared to result in cost savings for CCH.
- US 2 Rockfall Mitigation Project: The use of unit price pay items for the uncertain features of the scope allowed MDT to get as much rockfall mitigation completed as possible for the available funding. This was particularly significant because this project had a fixed price and had to be delivered without a contingency for differing site conditions.
- I-270 Slide Repair Project: DB project delivery permitted MoDOT to complete an emergency slide repair on the I-275 project in significantly less time than two previous DBB slide repair projects.

Limitations and Recommendations for Future Research

The study reported in this paper has found a number of interesting conclusions based on the rigorous analysis of three case studies. The conclusions are only applicable to the cases themselves and cannot be reliably generalized to all DB projects. Nevertheless, they do furnish a set of promising approaches for utilizing DB project delivery to address geotechnical risk and given the appropriate authority as well as the support by the requisite members of the agency chain of command provide a decent starting point for resolving individual geotechnical risk issues. Obviously, attempting to insert a "nested DB clause" into a DBB contract is an action that will require review and approval as well as the statutory authority to use DB. That being said, the three cases reported in this paper serve as an example of innovative approaches developed by

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agency professionals to manage the differing site conditions in a manner that keeps it from devastating a construction budget if the worst possible case is actually realized.

The above discussion leads to a recommendation that a larger, more comprehensive study of successful geotechnical risk management efforts be conducted to identify effective practices that can be generalized nationally. The output of that research would probably take the form of guidelines promulgated by a national sponsor such as the Federal Highway Administration or the American Association of State Highway and Transportation Officials.

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