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Analysis of Change Orders in Geotechnical Engineering Work at INDOT

Varenya Kumar Duvvuru Mohan
Purdue University - Main Campus, varenyakumar@purdue.edu

Monica Prezzi
Purdue University - Main Campus, mprezzi@ecn.purdue.edu

Bob McCullouch
Purdue University - Main Campus, bgm@purdue.edu

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ANALYSIS OF CHANGE ORDERS IN GEOTECHNICAL ENGINEERING WORK AT INDOT

Monica Prezzi
Professor of Civil Engineering
Purdue University
Corresponding Author

Bob McCullouch
Research Scientist
School of Civil Engineering
Purdue University

Varenya Kumar Duwuru Mohan
Graduate Research Assistant
School of Civil Engineering
Purdue University

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CORRESPONDING AUTHOR

Professor Monica Prezzi
School of Civil Engineering
Purdue University
(765) 494-5034
mprezzi@purdue.edu

JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

Change orders represent a cost to the State and to tax payers that is real and often extremely large because contractors tend to charge very large amounts to any additional work that deviates from the work that was originally planned. Therefore, efforts must be made to reduce significantly the occurrence of change orders in order to provide significant cost savings to the state of Indiana and save taxpayer dollars. The proposed research, in this context, developed a set of guidelines that will allow the geotechnical office of the Indiana Department of Transportation (INDOT) to minimize the probabilities of having change orders in those projects where they are truly preventable. These guidelines include not only recommendations on how to manage the problem of change orders associated with the geotechnical construction projects when they are unavoidable but also general recommendations wherever possible for adequate site investigation, design procedures, and quality assurance and quality control (QA/QC) processes that could help minimize change orders.

Based on the analysis conducted on the data collected from 300 INDOT contracts, it was found that the average geotechnical change order amount per district per year was 1.34 percent of the total estimated construction cost per district per year. The average geotechnical change order amount per district per year was 10.25 percent of the average amount of total change orders per district per year. The average net overrun due to geotechnical change orders was $707,000 per district per year. About 28 percent (84 contracts) of the contracts that were considered in this study experienced geotechnical change orders. In total, 158 geotechnical change orders were recorded in all the contracts. About 41 % of the total road contracts (155 contracts) experienced geotechnical change orders. About 37% of the total bridge contracts (44 contracts) experienced geotechnical change orders. The other contract types of this study's dataset were insignificant as far as geotechnical change orders were concerned. Reason code 206 – Constructability: Soils-Related – was assigned to 101 geotechnical change orders. Reason code 405 – Changed Field Conditions: Soils-Related – was assigned to 46 geotechnical change orders. Reason code 108 – Errors and Omissions: Soils-Related – was assigned to the 11 remaining geotechnical change orders. INDOT personnel who were interviewed acknowledged the fact that the variability of soil is so great that it would be literally impossible to eliminate geotechnical change orders. However, they did recognize the need to address the following issues that lead to geotechnical change orders (i) Failure to identify areas of poor subgrade soil (ii) Mismatch in piling quantities (iii) Omissions and constructability issues associated with erosion control work.

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ANALYSIS OF CHANGE ORDERS IN GEOTECHNICAL ENGINEERING WORK AT INDOT

Introduction

There was a perception at INDOT that the number of change orders connected with geotechnical work was excessive, and that, as a consequence, geotechnical projects were not completed on time or within budget. It was reported that INDOT construction projects had in fact experienced a large increase in the number and cost of change orders attributed to geotechnical conditions.

The only way to assess whether the number and cost of change orders to INDOT is indeed excessive is by conducting a detailed analysis of INDOT's processes and procedures in the geotechnical office, including the process of selecting code numbers that correspond to the reasons for change orders. It is only by understanding the reasons for change orders in each particular case that a determination could be made on whether change orders were preventable or not. Through this critical evaluation, problems that need to be addressed could be identified, and procedures or steps that should have been taken to allow prevention or minimization of change orders could be clearly established. This study organized the observations and information in a database. By analyzing the data collected and conducting interviews with INDOT personnel involved with change orders, recommendations were made to the geotechnical office for future procedures on construction projects that will help alleviate the problems identified.

Findings

The results of the agency survey conducted indicated that INDOT faired medially with respect to construction costs. The agencies provided very minimal data for change orders, and hence it was not possible to make clear comparisons. The analysis conducted on the data collected from 300 contracts of INDOT revealed some useful information. The average geotechnical change order amount per district per year was 1.34 percent of the total estimated construction cost per district per year. The average geotechnical change order amount per district per year was 10.25 percent of the average amount of total change orders per district per year. The average net overrun due to geotechnical change orders was $707,000 per district per year. About 28 percent (84 contracts) of the contracts that were considered in this study experienced geotechnical change orders. In total, 158 geotechnical change orders were recorded in all the contracts. Forty-six contracts (out of the 84 contracts that underwent geotechnical change orders) experienced only one geotechnical change order, while 24 contracts experienced 2 geotechnical change orders. About 41% of the total road contracts (155 contracts) experienced geotechnical change orders. About 37% of the total bridge contracts (44 contracts) experienced geotechnical change orders. The other contract types of this study's dataset were insignificant as far as geotechnical change orders were concerned. Reason code 206 – Constructability: Soils-Related – was assigned to 101 geotechnical change orders. Reason code 405 – Changed Field Conditions: Soils-Related – was assigned to 46 geotechnical change orders. Reason code 108 – Errors and Omissions: Soils-Related – was assigned to the 11 remaining geotechnical change orders. When compared to the total number of items that underwent change due to Errors and Omissions in all change orders (637), the occurrence of errors and omissions in geotechnical change orders is relatively low, which is a positive sign.

Most of the interviewees mentioned that they did not see geotechnical problems as the main contributor to change orders on INDOT projects. Though they acknowledged the fact that the variability of soil is so great that it would be literally impossible to eliminate geotechnical change orders, they did recognize the need to address the following issues that lead to geotechnical change orders:

1. Failure to identify areas of poor subgrade soil.
2. Mismatch in piling quantities.
3. Omissions and constructability issues associated with erosion control work.

Implementation

This research effort was directed towards initiating the process of identifying and addressing areas of concern that cause geotechnical change orders frequently on INDOT projects. Accordingly, the study provided some basic answers towards reducing the number of geotechnical change orders. The recommendations from this study could be considered at the planning stage of projects. With the help of the recommendations from this study it is possible to implement a methodology towards handling geotechnical change orders. Related studies could be conducted to formulate a refined methodology that includes all the recommendations in a suitable manner, in order to be implemented on a standard basis on all INDOT projects. Further research can be undertaken on analyzing individual reasons for geotechnical change orders to identify specific methods to avoid such issues.

Items for implementation:

1. The correct attitude of preventing change orders, rather than dealing with them, needs to be developed among one and all.
2. Reason codes for every change order have to be formulated free of ambiguity.
3. The geotechnical report must not only identify all problems but should also provide a discussion of all possible solutions to the geotechnical issues on the project.
4. For large projects, site investigation must be extensive and flexible, suitable to the particular soil type/region of state, to avoid subgrade treatment problems. In areas of problematic soil, the preliminary investigation should be followed by a secondary investigation with more number of boreholes.
5. The geotechnical engineer should coordinate with the design and district construction personnel while making recommendations.
6. Change orders related to geotechnical work should be routed through the geotechnical office so that the designer is made aware of the occurrence and the reason for the change orders.
7. Detailed constructability reviews, with the participation of the geotechnical office, must be conducted before the letting of major projects. Especially, traffic regulation and factors that can affect the quality of subgrade must be assessed from a constructability viewpoint.
8. Designers need to be aware of geotechnical foundation information, especially with respect to conditions below the subgrade so that they can include relevant items in the contract documents.
9. Impact of construction traffic in urban settings, needs to be accounted for in design.
10. Variation in moisture content from site investigation to construction should be accounted for in design.
11. Specifications need to be evaluated for constructability, before implementation.

12. Rock excavations must be accurate and the quality of rock must be well examined.
13. Shelved projects need to have a secondary site investigation. Anomalies during construction should also be sorted out through a second site investigation, with involvement of the geotechnical office.
14. More attention must be focused towards determining piling quantities accurately and suitable research could be conducted in this area.
15. An effective software system needs to be used to record change orders.

CHAPTER1. INTRODUCTION

1.1. Background

Almost all construction projects have a tendency to change as they progress. Change is normally defined as any event that results in a modification of the original scope, execution time, cost, and/or quality of the work (Ibbs et al. 2007). Accordingly, "change order" is the commonly used expression to refer to any change or variation from the original scope of work of the construction contract. A change order: 1) increases or decreases the scope of work, 2) changes specifications of the character or quality of the material, and/or 3) changes the level, position, or dimension of any part in the original contract of scope of work (Civitello 1987).

Change orders may occur frequently on construction projects for various reasons: 1) unexpected and unpredictable site conditions, 2) inadequate site investigation, 3) design errors, 4) weather conditions, 5) increases in project scope, and 6) other project changes. These factors have been known to affect the construction process in many ways depending on the contract type. According to Thomas et al. (1995) and Hanna et al. (1999), change orders typically tend to increase costs by extending the project duration or delaying the project process, and often cause labor productivity losses or significant inefficiency.

Change orders represent a cost to the State and to tax payers that is real and often extremely large because contractors tend to charge very large amounts to any additional work that deviates from the work that was originally planned. It is estimated that the United States construction industry spends \$13~26 billion each year for construction change orders (Ibbs et al. 1998). The total cost of project change could reach \$60 billion annually with additional financial resources spent on claims and legal disputes (Ibbs et al. 1998). Therefore, efforts must be made to reduce significantly the occurrence of change orders in order to provide significant cost savings to the state of Indiana and save taxpayer dollars.

The proposed research, in this context, developed a set of guidelines that will allow the geotechnical office of the Indiana Department of Transportation (INDOT) to minimize the probabilities of having change orders in those projects where they are truly preventable. These guidelines include not only recommendations on how to manage the problem of change orders associated with the geotechnical construction projects when they are unavoidable but also general recommendations for adequate site investigation, design procedures, and quality assurance and quality control (QA/QC) processes that could help minimize change orders. The main benefit from the present study is to provide cost savings to the State of Indiana by reducing the occurrence of geotechnical change orders.

1.2. Problem Statement

There was a perception at INDOT that the number of change orders connected with geotechnical work was excessive, and that, as a consequence, geotechnical projects were not completed on time or within budget. It was reported that INDOT construction projects had in fact experienced a large increase in the number and cost of change orders attributed to geotechnical conditions.

The only way to assess whether the number and cost of change orders to INDOT is indeed excessive is by conducting a detailed analysis of INDOT's processes and procedures in the geotechnical office, including the process of selecting code numbers that correspond to the reasons for change orders. It is only by understanding the reasons for change orders in each particular case that a determination could be made on whether change orders were preventable or not. Through this critical evaluation, problems that need to be addressed could be identified and procedures or steps that should have been taken to allow prevention or minimization of change orders could be clearly established. By organizing these observations and information in a database and by analyzing the data collected, recommendations could be made to the geotechnical office for future procedures on construction projects that will help alleviate the problems identified. This is what was done in this project.

1.3. Study Objectives

The main objective of the proposed research was to develop guidelines and to provide recommendations for minimizing the number of change orders related to geotechnical work at INDOT. Change orders related to geotechnical work for projects completed in the last 5 years were investigated and a database was compiled containing causes and effects of change orders for each project considered. The detailed goals of this research were as follows:

1. Collect and compile information on change orders for projects completed in the last 5 years that are directly related to work in the geotechnical field (information on the causes of these change orders are carefully evaluated).
2. Interview those who were involved in the projects in order to clarify specific details about each case.
3. Review the geotechnical work (site investigation, approaches used for treatment of "wet" or soft subgrade soils, foundation design, appropriateness of design methods, and QA/QC procedures) done based on the information provided by INDOT engineers during interviews on the causes of change orders in INDOT construction projects.
4. Prepare a database containing all geotechnical change orders in the last 5 years, and their causes. The database was organized by fields that included the number of change orders per project, construction cost, type of geotechnical work, geotechnical change order amounts and contract type.
5. Develop a set of guidelines for minimizing and reducing the occurrence of change orders caused by geotechnical conditions. The guidelines are comprehensive and focused on INDOT procedures and processes, and as a result they are also useful to contractors and owners trying to manage change better. The guidelines were

developed based on change orders in which a different approach to the geotechnical work would have prevented the change order or those in which a bureaucratic or process-related reason is apparent.

1.4. Scope of the Study

In order to accomplish the objectives of this research, several tasks were identified. The detailed scope of this research is as follows:

1. Perform literature review.
2. Compile the information available on each project for which there were change orders in the last 5 years directly related to work done by the geotechnical office (the information was organized by fields that included the number of change orders per project, construction cost, type of geotechnical work, project duration, and contract type).
3. Perform in-depth interviews with those who were involved in geotechnical change orders in the last 5 years to clarify or confirm details.
4. Review the geotechnical work (site investigation, foundation design, design methods used, QA/QC procedures used, and geotechnical construction procedures) related to change orders in INDOT construction projects.
5. Prepare a database containing change orders in the geotechnical office at INDOT in the last 5 years, their causes, and a final assessment on change orders preventability. Perform statistical analyses whenever possible for identifying the factors that have a significant influence on change orders in the geotechnical work done by INDOT.
6. Develop a set of guidelines and recommendations for the geotechnical office that will help minimize change orders and mitigate the impact of project changes in the future.

1.5. Report Organization

Chapter 1 of this report provides an overview of the situation at INDOT and the need for analyzing the occurrence of geotechnical change orders in INDOT construction projects. Also in Chapter 1, the objective of the study and its scope are described. In Chapter 2 the existing literature regarding change order and geotechnical change order occurrences are discussed. Some of the relevant results from previous studies are presented and discussed in the context of the data collected for this project. Chapter 3 presents the results from an agency survey aimed at understanding the causes of geotechnical change orders in other states. Chapter 4 presents the study approach and the framework for the analysis of the data collected. Chapter 5 describes the data collection process and the organization of the data into a form, such that it serves the purpose of this study. Chapter 6 provides the descriptive statistics from the data collected to elaborate on construction contract costs and geotechnical change orders. Chapter 7 presents the analyses performed on the data and the results from them. Chapter 8 quotes the information obtained from interviews performed with personnel associated with geotechnical change orders at INDOT. Chapter 9 provides a summary of the findings from the study. Chapter 10 presents the recommendations and discusses their implementation.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

This chapter includes a review of the identified literature on change orders, pertaining to geotechnical work. We also describe the many reasons for the occurrence of change orders and the methods used to manage or avoid change orders. A brief discussion of the most relevant studies and their findings are included in this chapter.

2.2. Prime Reasons for Change Orders

In general, the occurrence of change orders implies that there are certain issues in the project which have not followed their planned course (Rowland 1981). Considering the dynamic nature of construction projects, it would be impossible to eliminate the occurrence of change orders. There are very few projects that are completed without change orders. Thus, a reasonable objective for a project is to reduce the number of change orders and to manage changes more efficiently. According to Bordat et al. (2004), change orders may result in extra work that needs to be performed or in additional work to be carried out. Extra work was defined as work that need not necessarily affect project completion and that may not even feature as a part of the contract. Additional work, however, was defined as work that is caused by errors in planning and design, change in the scope of work or variation between estimated and actually required quantities. In order to reduce or prevent change orders in future projects, its causes need to be clearly identified.

With respect to specific reasons for change orders and influential factors, Rowland (1981) studied the data from 18 construction contracts. He concluded that contract size was a key factor that influenced the occurrence of change orders. According to Rowland (1981), an increase in the size of a contract, increased the change order rate. This conforms to the general idea that the complexity of a project increases with increases in project size, which in turn increases the change order rate. Rowland (1981) also suggests that in the case of larger projects, the length of the communication channel increases, leading to higher number of change orders due to shortcomings in transfer of information. Rowland (1981) also indicated through his research, the dependence of the number of change orders on the value of the lowest bid and the second lowest bid; the number of change orders rose when the winning bid was less than the government estimate.

Jacoby (2001) in alliance with FHWA, researched construction contract change orders. The study, which was completed in 2001, included 74 contracts that bore a cost greater than $10 million and cost overruns higher than 25% of the estimated contract cost. From the study, certain problems were identified to be the major reasons for the occurrence of change orders. These are listed in Table 2.1.

Observing the frequency of these reasons, the most common reason for the occurrence of change orders was found to be low engineer's estimate for the total construction project cost. Also, "differing site conditions – geotechnical issues (hazardous waste, soil excavation, additional shoulder rehabilitation required, additional pavement patching)" was a reason for change orders in 20 of the projects. This reason seemed to be one of the prime reasons for the occurrence of change orders. Since the change orders due to geotechnical issues are very relevant to the current research, we shall further elaborate on the literature pertinent to differing site conditions and also view some other reasons for change orders involving geotechnical work. The next section narrows down on the reasons that cause geotechnical change orders.

2.3. Geotechnical Reasons for Change Orders

A very broad view of the reasons for change orders was provided in the previous section. These issues might affect geotechnical work as much as any other type of work in construction. The focus of this study being to examine geotechnical reasons leading to change orders, it is necessary to understand the main geotechnical issues that are responsible for the occurrence of change orders.

2.3.1. Site Investigation

An effective site investigation program is of major significance in order to obtain all the necessary information required for construction on the field. The stability of pavements, slopes and foundations can be assessed with the data collected during site investigation. The greater the completeness of the site investigation program, the better the estimation of quantities on the plan and design stage and, the better the concurrence with actual quantities used for construction. Hence, a thorough site investigation program would ensure that the project sees fewer changes and change orders.

The failure to predict geological conditions and related geotechnical problems are prominent contributors to cost and schedule overruns on construction projects (Hoek and Palmeiri 1998). Cost and schedule overruns are mostly related to change orders in construction projects. Though attempts have been made to include contractual clauses to minimize overruns due to geological conditions, these efforts have proven to be futile in many cases. Thus, it is most profitable to be able to foresee these geological problems before hand. If all conditions could be foreseen and if design could cater to all the necessities, we would not have a necessity to change the course of the drafted plan. But the basic problem faced by a designer is the inadequacy of the information from the site investigation program.

In 1984, the U.S National Committee on Tunnel Technology (USNCTT) collected data from 84 tunnel projects and analyzed the influence of extent of site investigation on the cost increase in projects. Fig 2.1 shows the variation of cost versus the ratio of exploration borehole length to the length of the tunnel. From this plot it is evident that insufficient borehole drilling was directly related to cost increases. This can be clearly attributed to the inadequacy in the geological information at hand used to predict possible problems that may be encountered.

In the above case, tunnel projects were chosen. Obviously, the spacing of the boreholes along the length of the tunnel is also an important factor that needs to be accounted for because when widely spaced

TABLE 2.1
Reasons for Change Orders Identified by FHWA

Reason	Number of Projects	Remarks
Packaging of project	1	Project bundled with another
Design revisions between FHWA approval and actual advertisement	6	3 Projects in one state
Engineer's estimate was low/bid's high	27	Some fuel price adjustments, 1 project cited market conditions, some citations that size of project or uniqueness of work affected bid prices or state's ability to estimate project
Differing site conditions – geotechnical issues (hazardous waste, muck excavation, additional shoulder rehab required, additional pavement patching)	20	-
Environmental and legal injunction with construction delay costs	1	-
Low design-build estimates	3	-
Delays/accelerated roadway openings or work in general	10	-
Design issues corresponds to construction changes	5	Omissions, issues that carried over to construction
Payment of incentives	2	
Construction changes and miscellaneous or no reasons cited	13	Minor scope changes or additional work orders
Work zone traffic control	1	

Source: Jacoby 2001

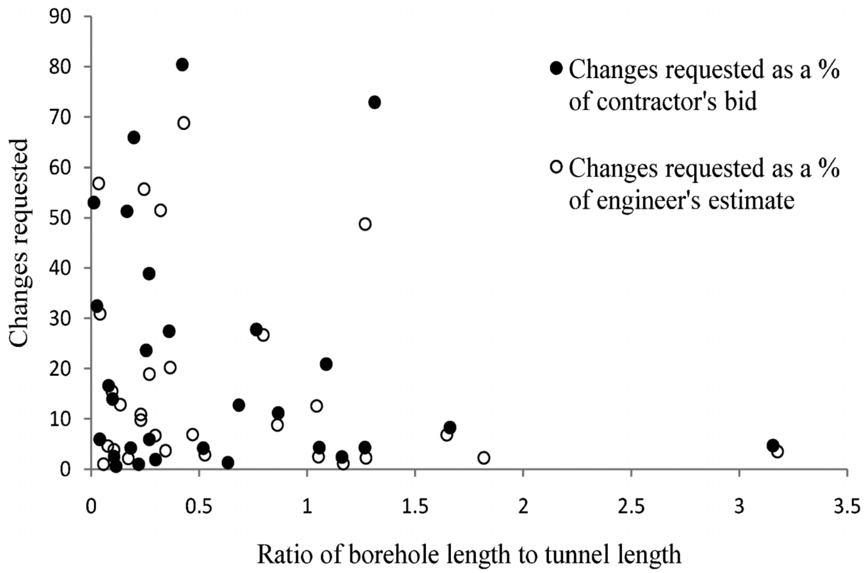


Figure 2.1 Variation of contract costs as a function of the length of exploration boreholes drilled (Source: USNCTT 1984)

boreholes are used, there is the need to interpolate the results between the boreholes. Basically, the geotechnical parameters evaluated at adjacent boreholes would have to be interpolated and in the case of excessive intermediate spacing, the interpolation will result in inaccurate data, which leads to surprises during construction and consequent change orders and cost overruns.

From this discussion it would be appropriate to state that site investigation inadequacies would increasingly affect projects that span several miles in length – long tunnels, long dams and more pertinently, highways.

We have seen unaddressed and unexpected site conditions as a reason for cost overruns and change orders. The next section discusses some of the other causes for change orders in geotechnical work.

2.3.2. Other Causes for Geotechnical Change Orders

Oxford English Dictionary defines "risk" as a situation which has a possibility of loss. Considering that change orders invariably result in an increase in construction cost and result in losses, any situation that can potentially lead to change orders can be referred to as a risk. Apart from unexpected site conditions, there could be other sources of geotechnical risks which lead to change orders. Some of these reasons may also be relevant to change orders involving any type of construction work.

Baynes (2010) classified the various types of geotechnical risks into the following categories:

1. Project Management Risk – caused by the poor management of the geo-engineering process due to lack of sufficient knowledge about the significance of ground conditions.
2. Contractual Risk – caused by poor management of site investigation and contract documentation due to lack of knowledge about the significance of the ground conditions.
3. Technical Risk

   a. Analytical - caused by the choice of an unreasonable analytical model.
   b. Properties - caused by the choice of unreasonable design values.
   c. Geological – caused by unforeseeable, inherently hazardous or unforeseen ground conditions.
   d. Errors in geotechnical design are another major cause for change orders. Trenter (2003) attributed geotechnical design risks on a construction project to three types of uncertainty, which coincide with the "Technical Risk" defined by Baynes (2010):

1. Design risks from uncertainty associated with geological issues.
2. Design risks due to uncertainty arising from the appropriateness of engineering analysis or the lack of it.
3. Risks associated with the reliability and representability of the engineering properties used in geotechnical design. The Los Angeles Unified School District (LAUSD) started a program in 2000 in order to construct over 150 new schools with a total construction cost of $1.5 billion. After the design phase of the project, the management sought to conduct a constructability review to mitigate further changes during the project. Pruett (2009) discussed the outcome and lessons from the constructability review conducted on this program. General statements about recommendations made in the geotechnical report used for the above mentioned project, were often found to be in conflict with the information provided in the earthwork specifications (Pruett 2009). The author also indicates the disregard for the change in conditions that occurred from the time of site investigation to the time of construction. In case of "performance" specification, it was seen that sometimes the designer placed the design-build responsibility on the contractor. When this was not clearly specified on the contract documents, it led to gaps in scope of work (Pruett 2009). These were some of the most relevant findings from the

constructability review conducted in the LAUSD program.

Having seen the various causes for geotechnical change orders, we will now look at some of the ways prescribed for preventing these change orders, as described in the literature.

2.4. Preventing Geotechnical Surprises

Considering the importance of site investigation, it would be obvious to conclude that a lot of time, effort and finances need to be concentrated there. However, a balance needs to be struck in determining the extent of site investigation. For example, the number of boreholes per unit length of the project needs to be determined. On a project of vast linear extent, it would be impossible to space holes very closely, as the costs would run very high. Even if boreholes were closely spaced, there would be no assurance that the entire soil profile would have been perfectly determined and there would still be opportunities for geotechnical surprises.

The next few sections discuss the approaches used in site investigation, as described in the literature, which may be helpful in establishing a balance between the resources spent through site investigation and the losses prevented by it.

Hoek and Palmeiri (1998) suggested methods to predict problematic geological conditions that when used have the potential to minimize cost overruns and change order occurrence. A brief description on their study and their prescriptions is presented here. One of the ways of avoiding unexpected geological and geotechnical issues, as suggested by them, is by using available local geological knowledge.

In all developed and in many developing countries, there are geological agencies which have accumulated information over the years and have data which reflect site conditions to a large extent. Thus, it is only obvious that construction projects should try to make use of the data collected by these agencies that have done extensive surveying over a number of years. Sometimes certain site locations are investigated as part of national development plans. In these well-investigated sites, only a small amount of additional data may be enough to set up design plans for certain projects.

In the absence of national plans or information available with national agencies, certain local universities and government mining departments are bound to have enough information on the local geology. It would be worth making an attempt to find such sources of information.

In case of dearth of such local knowledge, it is absolutely necessary to have a thorough geotechnical site investigation program that would allow an appropriate understanding of the soil conditions. Also, employing geotechnical experts with experience to carry out such site investigation is crucial to the success of the program itself (Hoek and Palmeiri 1998). In this regard, Professor Ralph Peck was quoted saying the following words of wisdom:

Nature did not follow standards in creating the mass of rock or soil in question. A defect or a field condition potentially fatal to the performance of the project may exist that escapes the standard investigation. Experience leading to judgment is the best defense against the consequences of such a possibility, and the course of action leading to an appropriate solution will differ amongst individuals of different experience. That is, judgment is an essential ingredient in geo-engineering, and it cannot be standardized.

Having already seen the importance of a sound site investigation program in minimizing change orders, we will now look into some of the ways and means to improve the quality of a site investigation program.

2.4.1. Advanced Methods to Enhance Site Investigation

The following are some methods described in detail in the literature that can be used to enhance a site investigation program:

1. Use of geophysical techniques like seismic reflection/refraction and mobile geophysical technology:

   Geophysical techniques are not replacements for traditional techniques, such as surface mapping, as primary site investigation tools. Seismic reflection or similar methods are of use when it comes to demarcating boundaries between weathered deposits closer to the surface and deeper bedrock. Cross-hole seismic techniques and tomography – imaging by sections through penetration of any kind of wave – are extremely useful tools for interpolating results between boreholes and for determining lithological boundaries (Hoek and Palmeiri 1998). However, the scope of geophysical techniques on a project, based on whether there are clear boundaries that the techniques can identify, should be assessed before their use at the site under consideration.

   Mobile geophysical techniques have a much wider range of applications than hand-held devices. In the case of hand-held devices used for geophysical techniques, the speed of data collection is very low and the data obtained is also sparse. Surface surveys can be carried out at a rapid pace with the use of mobile geophysical techniques that also produce dense datasets. Such data can be utilized to intelligently optimize the use of traditional drilling, through targeted and data-based subsurface exploration (Lopez 2006). Mobility and continuity in data acquisition are attributes that enable coverage of entire project area economically, ensuring that subsurface conditions are adequately assessed before construction.
2. Increased presentation of geotechnical information using 3-D modeling techniques (Hoek and Palmeiri 1998):

   Presentation of geotechnical information in three dimensions will considerably enhance the understanding of site conditions and, hence, help the designer to deliver more accurate designs and quantities that coincide with actual requirements during construction. Use of such technology is more widespread in the mining industry. Adoption of such techniques from the mining industry would help in enhancing the quality of geotechnical site investigation.

Despite recent developments in site investigation, the risk of changes will never be completely eliminated considering the random nature of soil. Thus, construction project contracts must address these risks effectively. The next section discusses contractual arrangements that help in managing these risks and, hence, aid in managing change orders better.

2.4.2. Contractual Arrangements to Manage Geotechnical risks

While the significance of the site investigation program was discussed, it was also seen that geotechnical risks tend to prevail despite robust site investigation. Moreover, considering the increasing emphasis on cost cutting measures and taking into account practical considerations, site investigation is bound to be an area of compromise. This makes it very essential to manage the risk of geotechnical surprises, with the help of contractual agreements.

The American Society of Civil Engineers (1997) prescribes that the risks associated with geological and geotechnical issues be reduced by:

1. Allocating an appropriate budget for obtaining subsurface information.
2. Employing or retaining experts who can evaluate the risks involved, prepare drawings and specifications, and also deliver a "Geotechnical Baseline Report (GBR)" that accounts for the risks involved. A GBR is a report that portrays a realistic interpretation of the subsurface conditions that are anticipated in the proposed construction, including the mean and expected variances of the prevailing geotechnical conditions (Smith 2001).
3. Preparing the Geotechnical Baseline Report by allocating ample time and financial resources to it and ensuring that it is consistent with other design documents.
4. Forming unit price payment provisions, keeping in mind that they need to be adjustable to varying conditions.
5. Reviewing and discussing thoroughly with bidders, the appropriateness of the bid, before it is submitted.
6. Reserving funds as a buffer depending on the gauged risk level on a project.

Implementation of such contractual agreements should help in managing risks to a great extent. This would be an effective way to handle the threat of change orders, geotechnical and others, on any construction project.

Other methods that are generally prescribed to control geotechnical change orders are:

1. Using "risk registers" for complete management of the geotechnical risks (Clayton 2001, Trenter 2003). Risk registers are documents that contain information on all the identified risks, their possible impact, probabilities of occurrence, planned responses when these are encountered and techniques to mitigate them.
2. Using various kinds of reports to methodically convey the results of the site investigation to the contractor (Knill 2003, Van Staveren & Knoeff 2004)
3. Having flexibility in the contract that allows the contractor to be paid for work that needs to be done (Fookes *et al.* 2000, Clayton 2001)
4. Using a contract that allocates the geotechnical risk, more or less equally, between the owner and the contractor (Eddleston *et al.* 1995)

Contractual arrangements, like the ones described above, help in addressing the various risks involved with geotechnical work on a construction project. Through the above methods, it can be ensured that there is a complete awareness and preparedness towards the risks associated with a project and that the aftermath of the risks, if encountered, is not concentrated just on the owner or the contractor, but equally divided among them. Apart from sharing risks and responsibilities, a contract document should act as a unifying force that ties both sides to a common objective, and the terms of the contract should primarily address that common objective. A strong contract document that clearly defines and identifies all the risks associated with the project, should go a long way in preventing change orders and resulting disputes that occur during the construction phase.

2.5. Summary

In this chapter we looked at the various studies that dealt with the problem of geotechnical change orders. The literature review identified the typical reasons, on a broad scale, that cause geotechnical change orders on construction projects and offered some suggestions to prevent or manage these changes in a cost-effective manner.

CHAPTER 3. AGENCY SURVEY

3.1. Introduction

An agency survey was carried out to obtain contract cost and geotechnical change order information from various states in the United States of America. The survey was motivated by similar efforts from Jacoby (2001) and Bordat et al. (2004) where information was collected from various DOTs. The agency survey on this research was conducted to form a basis of comparison with the change order data of Indiana and to gauge the relative standing of INDOT with regard to annual contract costs and geotechnical change orders. Also, data and information obtained regarding geotechnical reasons for change orders could then be compared to those provided in the literature review. An e-mail solicitation was distributed to all the 50 DOTs. The following information was requested:

1. The total annual construction cost
2. The total annual construction cost for geotechnical work
3. The total annual geotechnical change order cost
4. The major causes for the occurrence of geotechnical change orders

The above information was requested for each of the years in the period between 2003 to 2007. Replies were received from 8 states, which provided answers for some or all four of the above points, providing complete or partial data. This chapter presents and discusses the information received from these states.

TABLE 3.1
Requested information from California: 2003–2007

Question	2007	2006	2005	2004	2003
Total construction cost	$ 590.6	$ 1,574.7	$ 342.4	$ 470.1	$ 642.5
Total construction cost for geotechnical work	$ 177.2	$ 472.4	$ 102.7	$ 141.03	$ 192.75
Total cost of geotechnical change orders	$ 34.1	$ 8.7	$ 17.1	$ 26.0	$ 16.2
Benicia (Contract 04-006034)	$ 0	$ 61.0	$ 8.5	$ 135.2	$ 16.7

*All values in millions of dollars.

3.2. Contract Cost and Change Order Information: Results of Agency Survey

Eight states responded with information to our e-mail questionnaire – California, Georgia, Kansas, Kentucky, New Hampshire, Ohio, Virginia and Wisconsin.

The respondent from California provided the following data regarding the annual contract costs and geotechnical change orders amounts for the years 2003–2007, as shown in Table 3.1. It can be seen that the total construction cost was considerably more for the year 2006, as was the total geotechnical construction cost. However, the geotechnical change order cost was the greatest for the year 2007, at 34.1 million. The respondent separated the data for the city of Benicia in California, as recorded on the respondent's database.

Fig. 3.1 shows the variation of total annual contract cost, cost for geotechnical work (geo-items) and the geotechnical change order cost for 2003–2007 in the state of California.

The geotechnical change order amounts expressed as a percentage of the total construction cost for geotechnical work was seen to be highest for the year of 2007 (Fig. 3.2). The trend in change orders (as discussed in the literature) - change order amount increases with increases in construction cost - was not reflected in the data provided by the state of California. The occurrence of geotechnical change orders was greater in 2007 even though the geotechnical construction cost and the total construction cost were greater for the year 2006. The variation of geotechnical change orders as a percentage of the total construction cost and geotechnical construction cost is shown in Fig. 3.2.

As part of the survey, the agencies were also requested to list the main causes for geotechnical change orders in their state, as observed in their experience. The respondent from California provided the following reasons to be among the chief causes for geotechnical change orders in the state:

1. Man-made buried object
2. Differing site conditions
3. Design change (Examples: revised pile tip, revised pile type, revised pile size, revised footing dimension)

These reasons are very similar to the reasons discussed in the literature, which generally lead to geotechnical change orders.

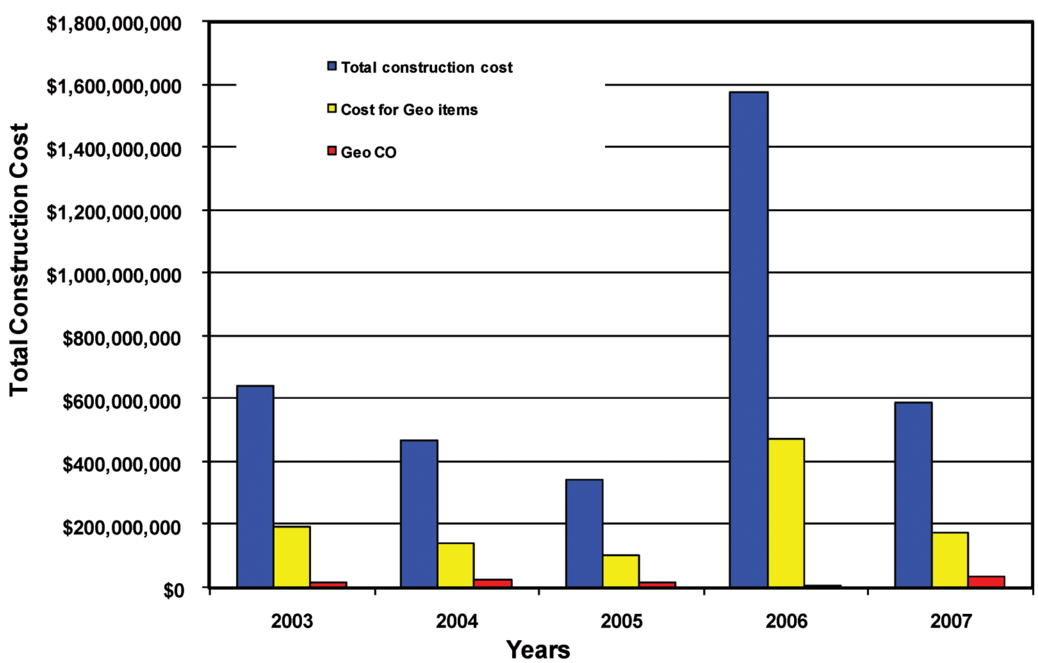


Figure 3.1 Variation of total construction cost, construction cost for geotechnical work, and geotechnical change order amounts for 2003–2007, California

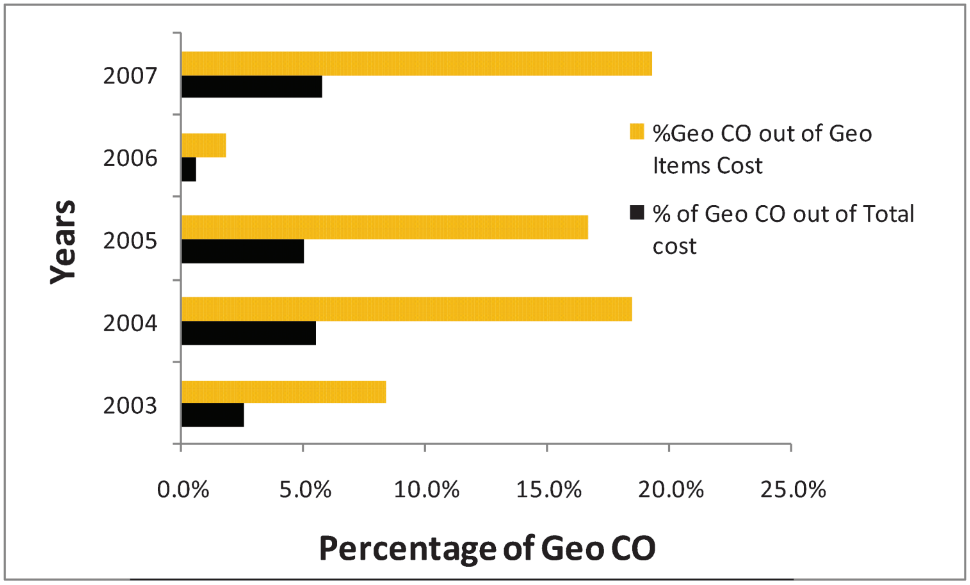


Figure 3.2 Variation of geo change orders as a percentage of total construction cost, geotechnical construction cost between 2003 and 2007, California

As mentioned previously, some of the states provided incomplete data in the reply to the information requested. The respondent from the state of Georgia replied with only the contract cost information for contracts in Georgia in the period between the years 2003 and 2007 (Table 3.2).

The respondent from the state of Kansas provided a more qualitative reply to the questions and did not respond with much of numerical data. In his reply, the respondent claimed that on projects where KDOT did the geotechnical work, the geotechnical change orders were 0 percent. On projects where geotechnical consultants from outside KDOT did the work, about 30 percent of the projects had change orders associated with geotechnical work, stated the respondent. Also, the reply mentioned that on an average, geotechnical change orders summed up to about $ 3 million, out of a $ 400 million construction budget. The respondent from Kansas also mentioned that though the change order rate was generally low, when they occurred, they tended to be very expensive.

The Kansas state reply stated that the main cause for geotechnical change orders, on their construction projects, was poor work from geotechnical consultants. Thus errors in design seemed to be the major issue, as far as geotechnical change orders in the construction projects of Kansas were considered. Though not much data was provided, the qualitative replies help in forming some idea about the geotechnical change order scene in the state of Kansas.

TABLE 3.2
Annual Construction Cost for Georgia: 2003–2007

Year	Total Annual Construction Cost
2003	$ 740,409,700
2004	$ 911,220,000
2005	$ 1,143,000,000
2006	$ 2,197,000,000
2007	$ 2,656,300,000

The respondent from Kentucky provided partial data for the annual construction costs for the projects in that state. Annual construction costs were provided for the years 2006 and 2007 (Table 3.3).

The main reasons for geotechnical change orders in Kentucky were stated to be:

1. Unexpected Site Conditions: Natural wet weather springs that were not detected during the site investigation, caused several minor landslides and settlement issues.
2. Unexpected Site Conditions: Varying rockline and fractures in the rock mass -Kentucky has several areas of karst that caused many problems during construction. Also, Kentucky has several areas with large rock cuts and, hence, unexpected fractures and joints caused problems.
3. Design Errors: Kentucky had fast-tracked several projects during the 6–7 years between 2002 and 2006, 2007. Several of the projects did not get as much review during the design phase as in the past and, as a result, more omissions and small errors slipped through.

These reasons, again, corroborate the claims from the literature that insufficient site investigation and design errors contribute majorly to the occurrence of geotechnical change orders.

The state of New Hampshire provided the data shown in Table 3.4. It can be seen from the data in Table 3.4 that the construction costs are evidently less than that compared to say, California. Understandably, the geotechnical change order costs are also correspondingly very much less or zero.

TABLE 3.3
Annual Contract Cost for 2006 and 2007

Question	2007	2006
Total construction cost	$1,543,443,088	$1,030,028,000

TABLE 3.4
Requested Data from New Hampshire: 2003–2007

Question	2007	2006	2005	2004	2003
Total construction cost	$96,798,300	$133,142,500	$133,737,700	$112,965,900	$119,284,900
Total construction cost for geotechnical work	$1,519,200	$889,100	$2,685,700	$1,528,300	$2,154,100
Total cost of geo-co	$0	$0	$0	$12,200	$78,300

Fig. 3.3 shows the variation of annual construction cost and geotechnical construction cost across the years 2003–2007, New Hampshire.

The main reason for geotechnical change orders in construction contracts in New Hampshire was quoted to be unexpected site conditions that were encountered on the field.

The data from the state of Ohio is shown in Table. 3.5. The year with highest construction cost, 2005, was also the year with the highest amount of geotechnical change orders. However, the geotechnical change order amounts as a percentage of the total construction cost was highest for the year 2003. This again does not necessarily conform to the trend discussed in the literature, where construction costs have been identified to be an influential factor on change order amounts.

The annual construction costs in the state of Ohio for the years 2003–2007, varied as shown in Fig. 3.4. Also shown are the total construction cost for geotechnical work (geo -items) and the geotechnical change order amounts. Fig. 3.5 shows the variation of the geotechnical change order amounts expressed as a percentage of the total annual construction costs and as a percentage of geotechnical construction cost for 2003–2007.

The respondent from the state of Virginia did not provide any data for the construction costs or change orders. However, he provided the major two reasons for the occurrence of change orders in geotechnical work for construction contracts in the state of Virginia:

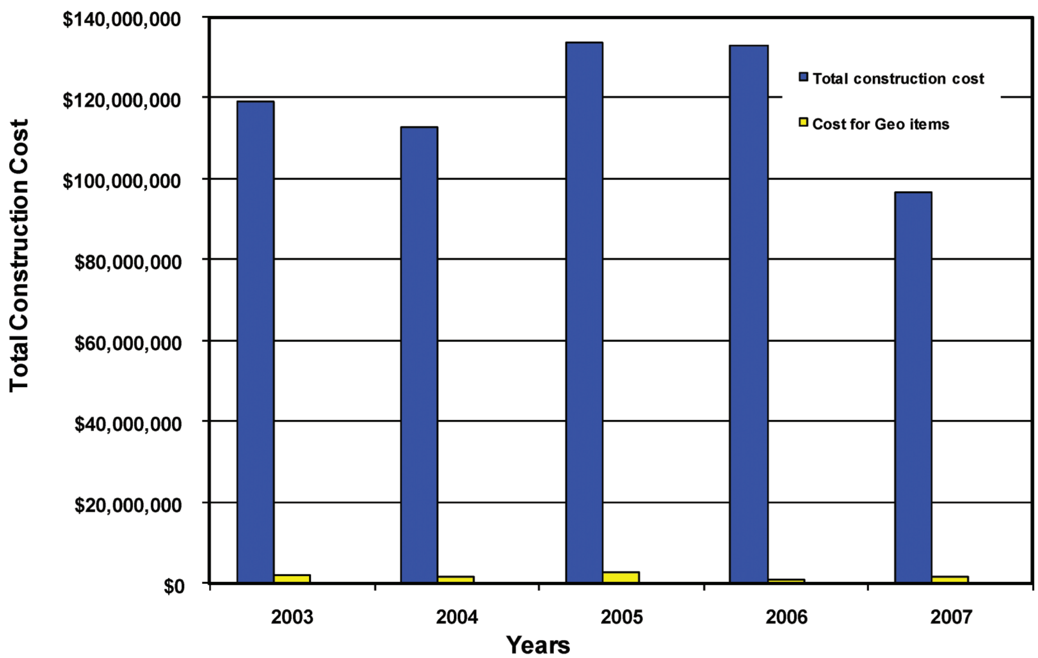


Figure 3.3 Variation of total construction cost and geotechnical construction cost in New Hampshire: 2003–2007

TABLE 3.5
Requested Data from Ohio: 2003–2007

Question	2007	2006	2005	2004	2003
Total construction cost (millions of dollars)	1,210	1,560	1,170	1,130	920
Total construction cost for geotechnical work (millions of dollars)	101	69	130	80	84
Total cost of geotechnical change orders (millions of dollars)	18.2	8	17.90	31.3	40.5

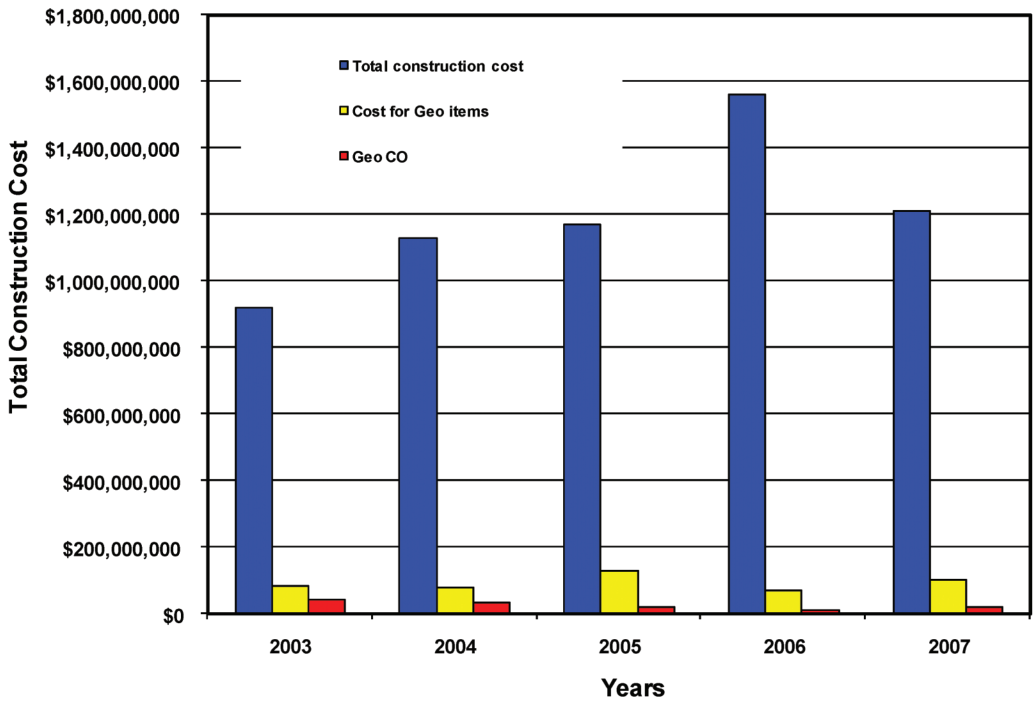


Figure 3.4 Variation annual construction cost, geotechnical construction cost and geotechnical change order amounts for 2003–2007, Ohio

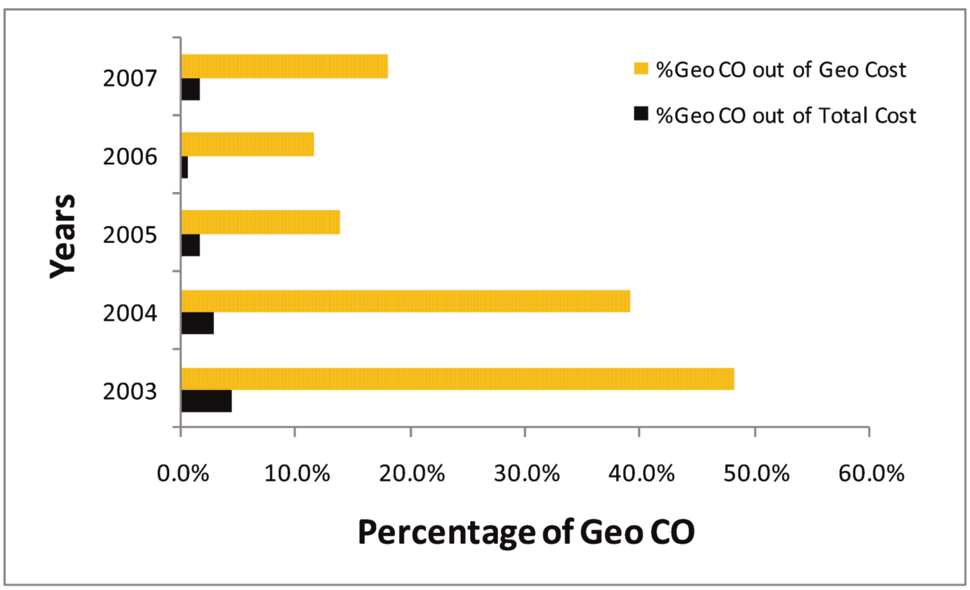


Figure 3.5 Variation of geotechnical change order amounts as a percentage of total construction costs and geotechnical construction costs between 2003 and 2007: Ohio

1. Occurrence of unsuitable materials and their undercutting
2. Contract items (pay items and quantities)

Again, these two reasons point at improper site investigation and design errors.

The respondent from Wisconsin provided the data for the annual construction costs for 2005–2007 (Table. 3.6) but there was no information on geotechnical work in the state.

The main reasons for occurrence of geotechnical change orders in construction contracts in the state of Wisconsin are:

TABLE 3.6
Annual Construction Costs in Wisconsin: 2005–2007

Question	2007	2006	2005
Total construction cost	$725,000,000	$715,000,000	$715,000,000

TABLE 3.7
Data from Indiana States with district-wise split: 2003–2007

Year	Total construction cost for Indiana	Crawfordsville	FortWayne	Greenfield
2003	$485,076,967	$15,067,837	$61,599,742	$146,222,558
2004	$666,372,736	$36,391,559	$117,844,773	$213,946,865
2005	$756,216,354	$63,496,574	$67,021,701	$261,900,815
2006	$635,789,041	$70,763,194	$132,215,237	$250,471,375
2007	$695,204,894	$49,876,534	$52,152,381	$150,415,505
Average	**$647,731,998**	**$47,119,140**	**$86,166,767**	**$204,591,424**

Year	LaPorte	Seymour	Vincennes
2003	$135,430,544	$70,274,216	$56,482,070
2004	$119,838,736	$102,051,125	$76,299,678
2005	$131,971,540	$153,647,239	$78,178,484
2006	$26,586,361	$58,472,606	$97,280,267
2007	$146,762,935	$57,481,395	$238,516,144
Average	**$112,118,023**	**$88,385,316**	**$109,351,329**

1. Unexpected site conditions and conditions that change from the time of site investigation to the time of construction
2. Misinterpretation and misunderstanding of specifications
3. Design changes

Table 3.7 shows the data for the annual construction costs in the state of Indiana and also gives the split among the six districts in the state.

Combining all the data from the states, Fig. 3.6 shows the variation of annual construction costs for 2003–2007 of each of the states that turned in considerable amount of data. It is clear that Georgia is ahead in terms of the annual construction cost. Indiana has comparable construction costs with the state of Wisconsin.

3.3. Summary

Though the response from the DOTs around the country was very minimal, the agency survey provided some useful information on the trends of the construction costs in some of the states and how they compared to Indiana. Also, more crucially, some main causes for the occurrence of geotechnical change orders in these states were identified. The most common causes were:

1. Unexpected site conditions due to insufficient site investigation
2. Design changes and errors
3. Change in field conditions
4. Man-made buried objects
5. Contract items – payments and quantities

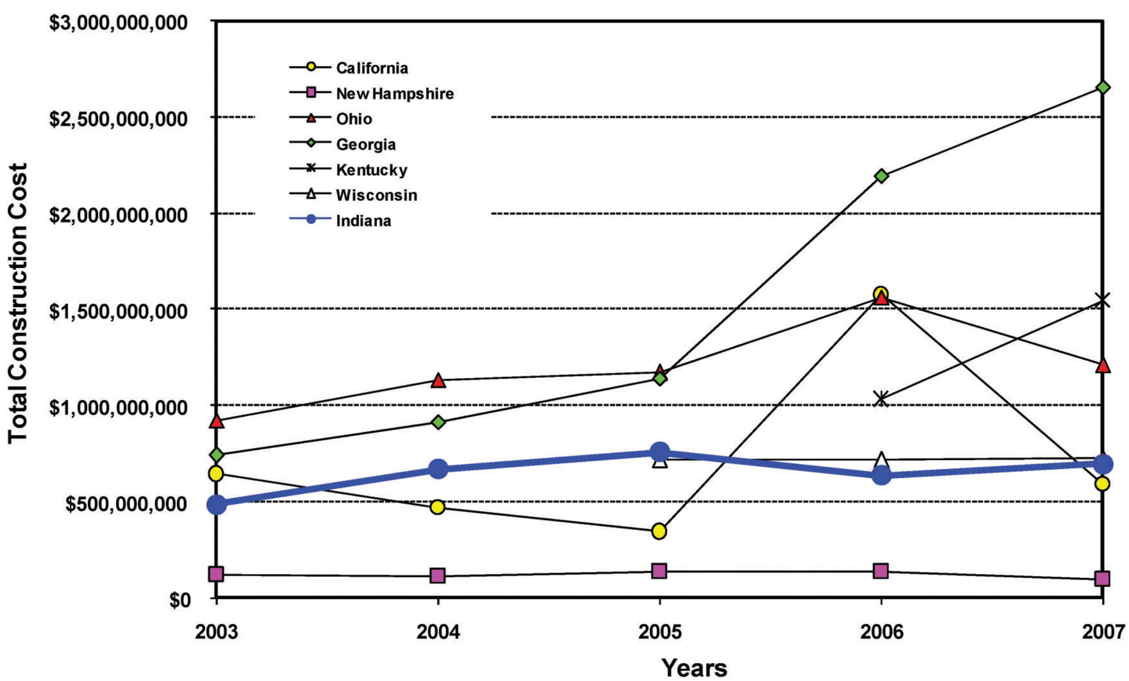


Figure 3.6 Comparison of annual construction costs between states for 2003–2007

The agency survey gives us a preview into some of the reasons that may be causing geotechnical change orders in INDOT projects and also gives a basis of comparison for the data from construction contracts in Indiana, which is discussed in the next chapters.

CHAPTER 4. STUDY METHODOLOGY AND DATABASE FORMATION

4.1. Introduction

In order to investigate the occurrence of geotechnical change orders in Indiana, a method of study was established to work within the limits of data availability. This chapter discusses the method of study that was adopted to investigate the causes of change orders in geotechnical work in INDOT projects. The collection of data, the form of its availability, the process of sorting of the data, its presentation and the analysis performed on the data are described in this chapter.

4.2. Method of Study

The following sequence of steps was adopted as part of the methodology for analyzing the change orders in geotechnical work at INDOT:

1. Six districts of Indiana were chosen based on similar analysis of change orders at INDOT, previously performed by Bordat et.al (2004).
2. Material related to change orders in INDOT projects was collected from the district offices of INDOT.
3. Data relevant to the change orders in geotechnical work was selected from the material collected in step (1).
4. The data from step (2) was then sorted out into a meaningful and presentable form to create the database of geotechnical change order information.
5. Descriptive statistics were used to represent the data in a tangible manner, from which conclusions could be drawn regarding the change order trends and reasons for occurrence.
6. Interviews were conducted with some of the project engineers and geotechnical consultants who were involved in the geotechnical work and the associated change orders in some of the projects that were part of the database.
7. Results and inferences were obtained from the descriptive statistics and the interviews performed.
8. Recommendations were formulated based on the data collected to help INDOT minimize the problem of geotechnical change orders.

4.3. Database Formation

As described in the methodology section above, this study began with the collection of data from district offices of INDOT and further processing of the data into an appropriate form. In accordance with the study objectives, this study used the data from certain INDOT contracts that were completed in the five years between 2003 and 2007. These contracts essentially had end dates which fell in the five years that were considered. The top ten contracts, in terms of the estimated total construction cost, from each year from each district were selected. Hence, the dataset included ten contracts from each of the five years between 2003 and 2007, from each of the six districts in Indiana. In all, data from 300 contracts were part of the database. In the next section, we will look into the processes and the rationale behind the development of the dataset.

4.3.1. Collection of Material

As mentioned earlier in Section 4.2, six districts were chosen from the state of Indiana. The contract documents of each of the 300 contracts (50 from each district) were collected from the district offices of INDOT. For this study, the six districts that were considered are Crawfordsville, Fort Wayne, Greenfield, LaPorte, Seymour and Vincennes. Figure 4.1 shows the geographic location of the six districts.

The contract documents typically contained the following relevant information:

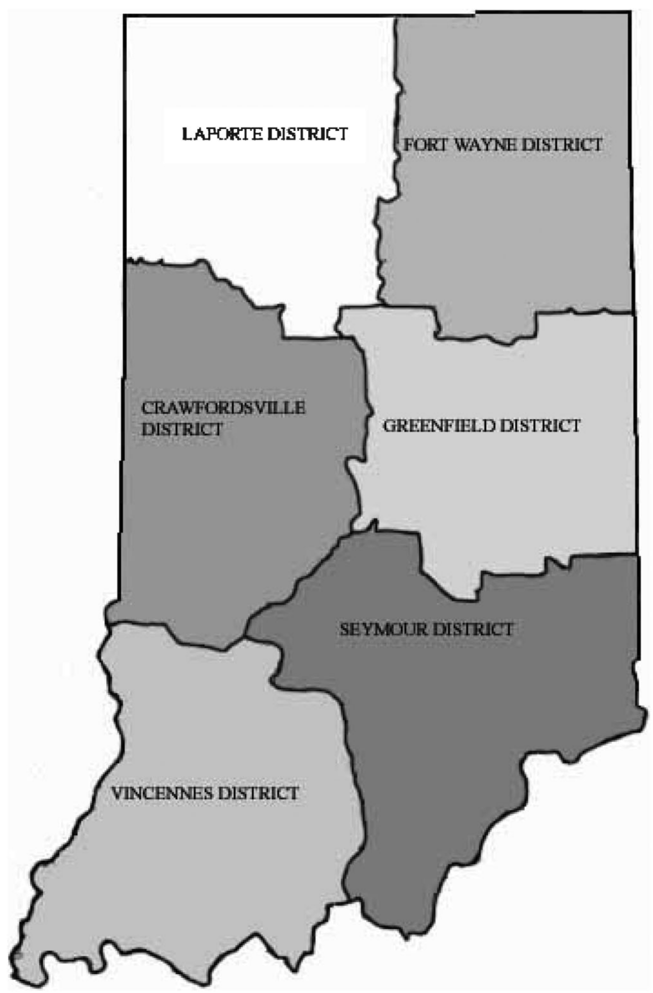


Figure 4.1 Highway Administrative Districts in Indiana (Bordat et.al 2004)

1. A brief description of the change orders that occurred on the project:

   This includes a few lines of information as to what caused the change order and what work was being carried out that had not been planned earlier.

2. The reason code assigned to each of the change orders:

   Every change order was assigned with a particular reason code, according to the standard reason codes followed in INDOT contracts; this is explained in detail in Sections 4.3.2 and 4.3.3.

3. The amount involved in the change orders in U.S. Dollars.

In addition to the estimated total construction costs for the projects selected, the above three bits of information were collected from each of the 300 contract documents and stored in Microsoft Excel Spreadsheets.

4.3.2. Change Order Policy and Reason Codes at INDOT

We have already seen from the literature review in Chapter 2 and the Agency Survey in Chapter 3 that change orders occur as a result of factors such as unexpected changes in field conditions, changes in project scope and design errors. But all changes are not recorded as change orders. This section describes the change order policy and reason codes that are followed in INDOT contracts. INDOT's "Policy for Construction Change Orders on Highway Construction Contracts" (refer Appendix) defines the circumstances for recording change orders and also prescribes reason codes that need to be attributed to these. This enables us to understand better the circumstances that warrant recording of change orders and the possible categories of change orders, classified based on typical reasons.

The Policy requirements, described in detail in INDOT's "Policy for Construction Change Orders on Highway Construction Contracts" (refer Appendix), include the following with respect to recording of change orders:

- "**1.1.** A Change Order is not required, within the limits set out below, to authorize minor changes in original contract pay item quantities that are typically necessary to meet the scope and design of the contract. Once any one of the limits below is exceeded a Change Order shall be generated to authorize the revision. The Change Order shall include all revisions to original contract pay item quantities not previously addressed by a Change Order. Additional Change Orders due to further changes in original contract pay item quantities are not required until the limits of this section are again exceeded.
- **1.1.1** $20,000 sum total change in any one original contract pay item.
- **1.1.2** The greater of $20,000 sum total change in all contract pay item quantities or a sum total change of 2% of the original contract amount in all original contract pay item quantities, not to exceed $250,000."

Hence, change orders are recorded on INDOT projects under the above conditions. In order to enable INDOT to manage changes better in future, all change orders are assigned a reason code that indicates the reason for the occurrence of the change order. All items on a particular change order are assigned the same reason code. The following is a summary of the reason codes used at INDOT:

1. Contract Documents Errors and Omissions (codes 101 to 111): An error or omission in the contract documents which prevents the contract to be constructed as intended.
2. Scope Changes (codes 301 to 309): A change in the project limits or design that revises the original intent of the contract.
3. Changed field Conditions (codes 401 to 407): Either an existing or new condition that could not have been reasonably foreseen either by INDOT or the contractor prior to beginning the work.
4. Failed Material (code 500): Material failures that result in penalties, reduced payment of items of work.
5. Standard Changes (codes 701 to 703): A change in the contract specifications as a result of an INDOT department decision to initiate changes to active contracts on a statewide basis.

A comprehensive list of all the reason codes is shown below in Table 4.1.

Using the above information, we will next see how the pertinent data from the 300 contracts were selected and sorted.

4.3.3. Data relevant to geotechnical work

As far as identifying the data related to geotechnical work, all the soil-related works that included soil-related items such as aggregate, backfill, backfill borrow, debris removal, erosion, excavation, geogrids, geotextiles, linear grading, riprap, stone, sub-base, sub-grade, tie bars and top soil were identified, and the associated bid amounts and change order amounts were stored as part of the dataset. The lack of precise descriptions and reason codes that would allow proper identification of root causes necessitated such a wide classification of soil-related work. However, all the change orders associated with soil-related items were not necessarily due to geotechnical reasons. For example, in case of costs associated with excavation and aggregates, the reasons could either be geotechnical in the case where soil treatment (undercutting and replacement) was not mentioned in the plans. However it could also be due to other reasons where there was a scope change in the project and hence more aggregate and excavation was required or the recycled pavement which was supposed to be used for filling was not sufficient. Hence, the change orders associated with soil-related items needed to be further classified to ensure that we narrow down to the change orders that are precisely caused by geotechnical reasons.

TABLE 4.1
Reason codes at INDOT

Reason code	Reason for Change Order
101	Error & Omissions: Contract Documents, Contract Related
102	Error & Omissions: Contract Documents, Design Related
103	Error & Omissions: Contract Documents, Environmental Related
104	Error & Omissions: Contract Documents, Materials Related
105	Error & Omissions: Contract Documents, Permits
106	Error & Omissions: Contract Documents, Quantity Related
107	Error & Omissions: Contract Documents, R/W Related
108	Error & Omissions: Contract Documents, Soils Related
109	Error & Omissions: Contract Documents, Staging Related
110	Error & Omissions: Contract Documents, Traffic Control Related
111	Error & Omissions: Contract Documents, Utilities Related
201	Constructability: Construction Related
202	Constructability: Design Related
203	Constructability: Environmental Related
204	Constructability: Materials Related
205	Constructability: R/W Related
206	Constructability: Soils Related
207	Constructability: Staging Related
208	Constructability: Traffic Control Related
209	Constructability: Utilities Related
301	Scope Changes: FHWA
302	Scope Changes: Central Office Construction/ Traffic
303	Scope Changes: District/ Sub-district
304	Scope Changes: District Construction Engineer
305	Scope Changes: Area Engineer
306	Scope Changes: Project Engineer/ Supervisor
307	Scope Changes: Traffic Engineer
308	Scope Changes: Local Agency request
309	Scope Changes: Public/ Political Request
401	Changed Field Conditions: Construction Related
402	Changed Field Conditions: Environmental Related
403	Changed Field Conditions: Materials Related
404	Changed Field Conditions: R/W Related
405	Changed Field Conditions: Soils Related
406	Changed Field Conditions: Staging Related
407	Changed Field Conditions: Utilities Related
500	Failed Material
601	Incentive/ Disincentive: Contract Completion Time
602	Incentive/ Disincentive: Contract Payments
603	Incentive/ Disincentive: Cost Reduction
604	Incentive/ Disincentive: A+B Contract
605	Incentive/ Disincentive: A+B+C Contract
701	Standards/ Specs: Update or Changes, Contract Completion Time
702	Standards/ Specs: Update or Changes, Contract Payments
703	Standards/ Specs: Update or Changes, Other

4.3.4. Sorting of data related to geotechnical work

In order to identify the change orders with geotechnical reasons, the change orders with reason codes the following reason codes were classified separately, as geotechnical change orders. These reason codes were:

1. 108 - Errors and Omission Contract document: Soils Related
2. 206 - Constructability: Soils Related
3. 405 - Changed Field Conditions: Soils Related

After filtering the data based on the reason codes, all the change orders that were that had the above three reason codes, i.e., the geotechnical change orders, were planned to be further broken down in the following manner:

1. Geotechnical change orders that occurred in contracts where the geotechnical work was directly under the supervision of the state (managed by the Geotechnical Division at INDOT) – were to be referred to as STATE contracts.
2. Geotechnical change orders that occurred in contracts where the geotechnical work was performed by local consultants – were to be referred to as LOCAL contracts.

However due to the lack of specific information at INDOT that indicated whether the state handled the geotechnical work on a particular project or not, all the contracts could not be classified into STATE and LOCAL contracts. Hence this classification was not included in the database or the data analysis.

4.4. Descriptive Statistics

This study seeks to identify the frequency of geotechnical change orders and the main reasons responsible for these changes. Accordingly, it was anticipated that a descriptive statistical analysis on the data would shed some light on the variation of construction costs and change order costs across districts and project types, frequency of geotechnical change orders, the costs involved, the reasons for their occurrence and the frequency of these reasons. Simple graphs that show variation of these quantities show the general trend they follow. Bar graphs and pie charts help in providing a visual indication of the costs involved and the frequency of geotechnical change orders and their reasons. Also, the relative standing between districts, contract types and reason codes could be assessed through such graphs. Hence, the use of such descriptive tools to analyze the data will provide a platform for making inferences about geotechnical change orders trends. The descriptive statistics that were prepared for the dataset are presented in Chapter 5.

4.5. Interviews

Apart from analyzing the data from the contracts, the opinion of people who were involved with these change orders and work day to day on INDOT contracts, would be invaluable towards understanding the geotechnical change order situation on INDOT projects. In order to further scrutinize the topic and understand exactly how and why geotechnical change orders occur, and how they are managed, interviews were conducted with personnel linked closely with geotechnical change orders on INDOT contracts. Project Engineers who worked on some of the contracts that are part of this study and geotechnical consultants who work on INDOT projects on a regular basis were contacted and interviewed. The interviewees were requested to provide information regarding the geotechnical change orders on the contracts they worked on and also other geotechnical change orders they have come across in their experience. The information gathered and the results from these interviews are presented in detail in Chapter 6.

4.6. Summary

This chapter discussed the method of study adopted in order to investigate the problem of geotechnical change orders. The process of collection of material and it's basis were described. The selection of relevant data from all the material that was collected was discussed and the rationale behind it was explained. The sorting of the dataset, in order to be able to perform suitable analysis, was elaborated upon as well, in this chapter. Also the proposed analysis of the data, using descriptive statistics, was also briefly discussed. Further, the need for talking to personnel involved with geotechnical change orders at INDOT was discussed and a accordingly, a mention was made regarding interviews that were conducted with INDOT project engineers and geotechnical consultants who work on INDOT projects. The next chapter presents in detail all the descriptive statistical analysis conducted on the data, which will help us in obtaining useful inferences regarding geotechnical change orders at INDOT.

CHAPTER 5. DESCRIPTIVE STATISTICS

5.1. Introduction

In the previous chapter, we looked at the study methodology in detail. With the available data, the geotechnical change order information across the six chosen IN districts is presented in this Chapter in the form of scatter plots, bar graphs and pie charts. These graphs will enable us to visualize the trends followed by change orders in the districts of Indiana. With the inferences from these graphs and the results of the interviews described in the next Chapter, we will be able to reach useful conclusions and to propose recommendations for preventing or managing geotechnical change orders better. As mentioned in the previous chapter, the data was collected from the top ten contracts(in terms of total construction cost) of six districts in Indiana(all contracts ended in the five years between 2003 and 2007). The various classifications that are part of the graphs are based on (i) the different districts – Crawfordsville, Fort Wayne, Greenfield, LaPorte, Seymour and Vincennes; (ii) types of projects – road, bridge, resurfacing and maintenance (due to the

TABLE 5.1
Variation of estimated total annual construction cost and estimated total annual cost for soil-related items in all districts: 2003–2007

Category	Year	District (amounts in thousands of dollars)						
		Crawford-sville	Fort Wayne	Green-field	LaPorte	Sey-mour	Vince-nnes	Average
Final Construction Cost (Top ten contracts)	2003	8,583	28,596	80,212	40,694	65,142	37,429	43,442
	2004	16,112	27,671	104,863	37,064	79,209	26,282	48,534
	2005	29,448	38,699	91,871	71,451	54,909	36,720	53,849
	2006	30,892	73,828	93,815	17,752	14,411	44,002	45,783
	2007	25,039	17,039	62,126	47,332	36,635	178,915	61,181
Cost of Soil-related Items	2003	588	3,488	10,941	5,656	13,590	4,614	6,479
	2004	1,508	2,472	13,631	4,461	18,611	5,032	7,619
	2005	3,484	5,875	28,030	6,681	11,303	8,612	10,664
	2006	6,681	10,536	16,575	1,760	2,006	10,511	8,012
	2007	3,443	2,688	8,478	5,409	3,437	33,754	9,535
Soil-related Items as Percentage of Construction Cost	2003	6.85%	12.20%	13.64%	13.90%	20.86%	12.33%	14.92%
	2004	9.36%	8.93%	13.00%	12.04%	23.50%	19.15%	15.70%
	2005	11.83%	15.18%	30.51%	9.35%	20.59%	23.45%	19.80%
	2006	21.63%	14.27%	17.67%	9.92%	13.92%	23.89%	17.50%
	2007	13.75%	15.77%	13.65%	11.43%	9.38%	18.87%	15.58%

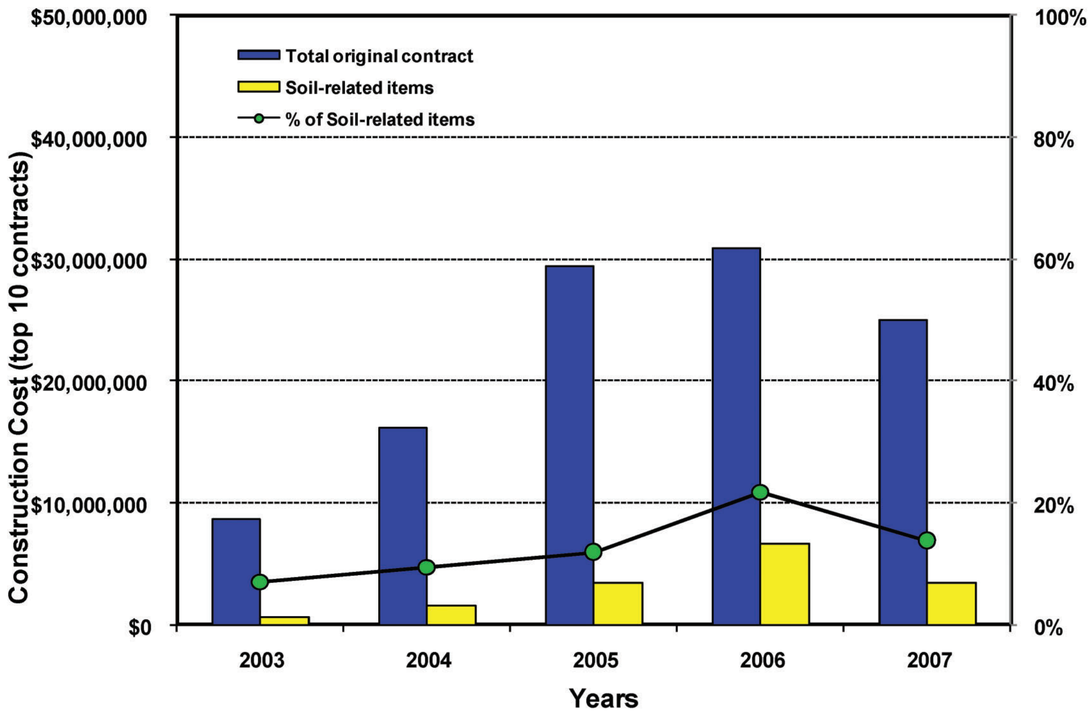


Figure 5.1 Variation of total construction cost, cost of soil-related items, soil-related items as a percentage of construction cost between 2003 and 2007– Crawfordsville

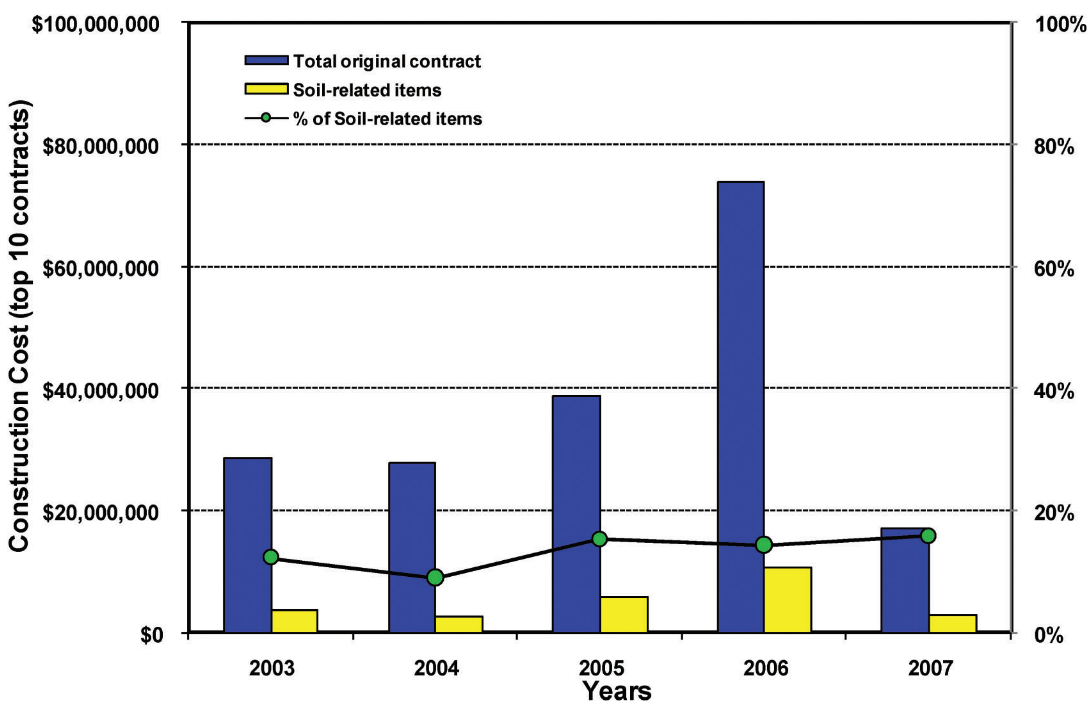


Figure 5.2 Variation of total construction cost, cost of soil-related items, soil-related as a percentage of construction cost between 2003 and 2007– Fort Wayne

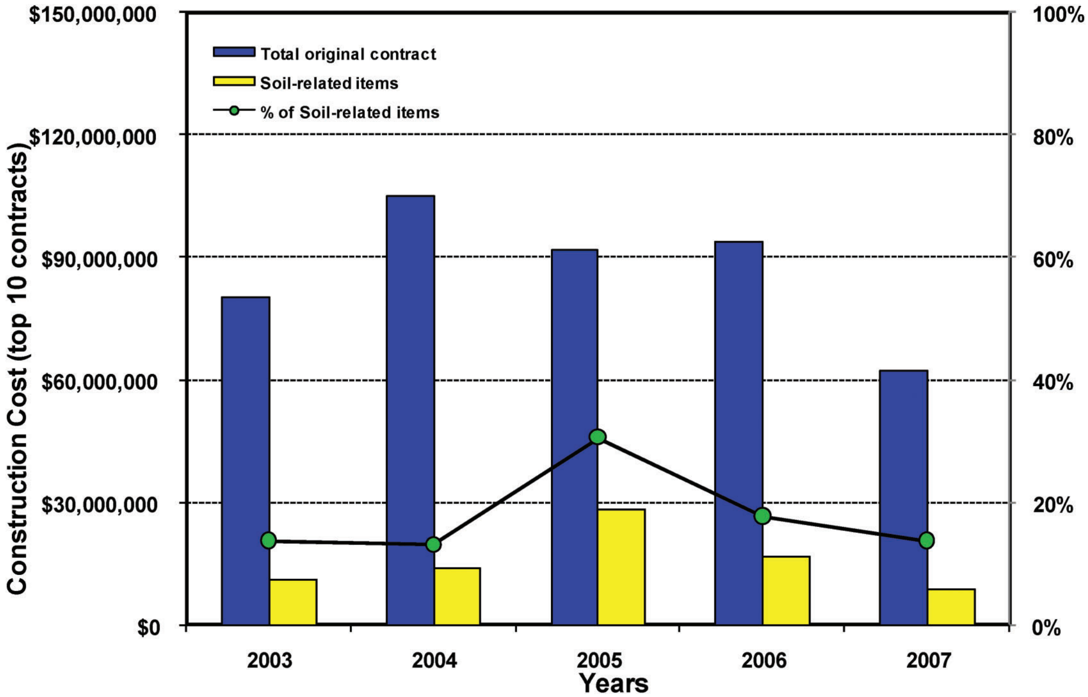


Figure 5.3 Variation of total construction cost, cost of soil-related items, soil-related items as a percentage of construction cost between 2003 and 2007 – Greenfield

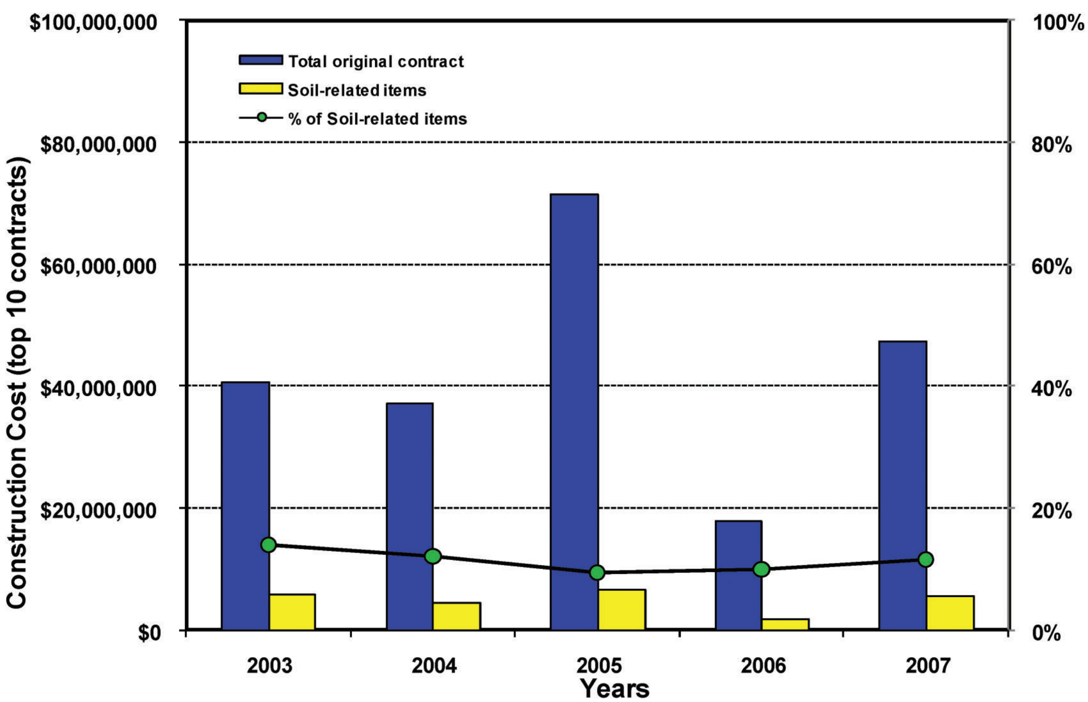


Figure 5.4 Variation of total construction cost, cost of soil-related items, soil-related items as a percentage of construction cost between 2003 and 2007 – LaPorte

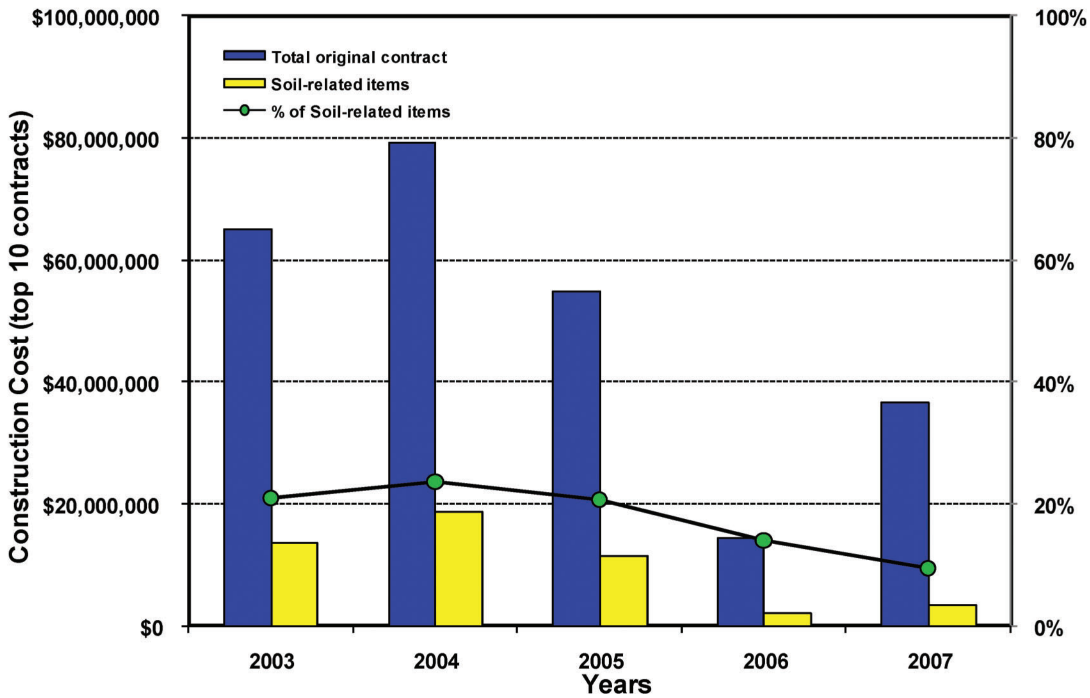


Figure 5.5 Variation of total construction cost, cost of soil-related items, soil-related items as a percentage of construction cost between 2003 and 2007 – Seymour

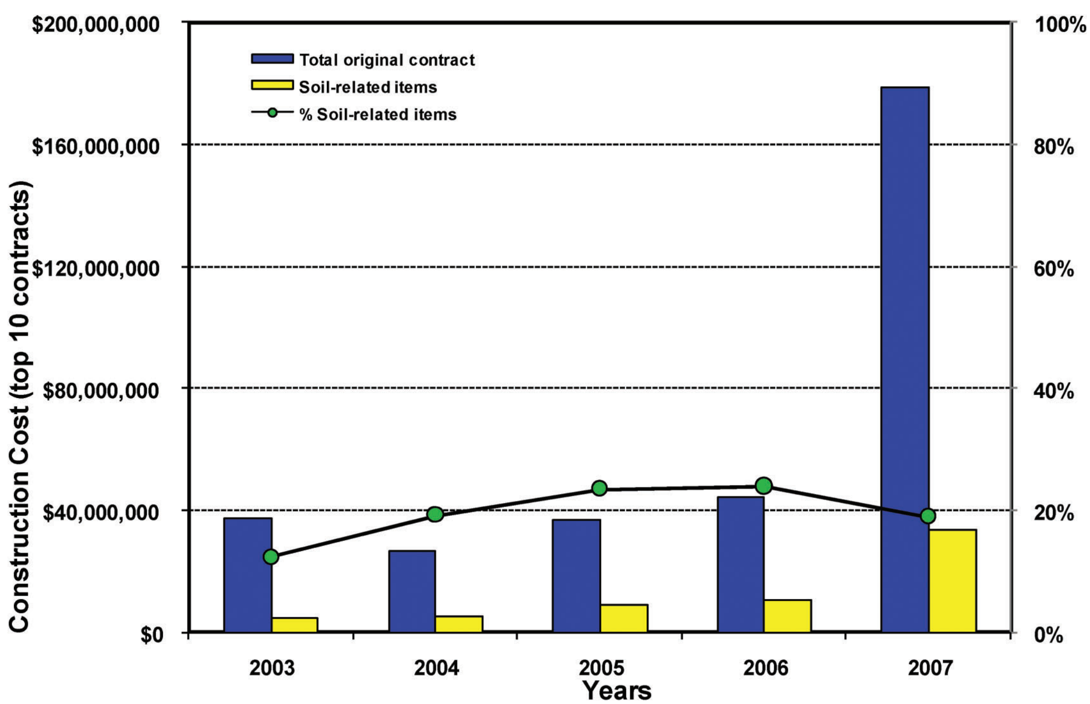
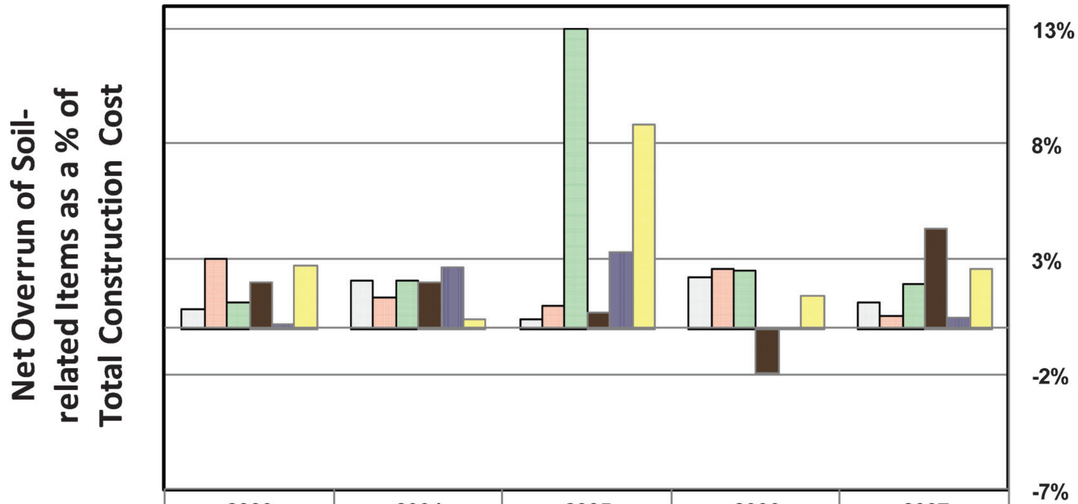


Figure 5.6 Variation of total construction cost, cost of soil-related items, soil-related items as a percentage of construction cost between 2003 and 2007 – Vincennes



	2003	2004	2005	2006	2007
Crawfordsville	0.86%	2.08%	0.40%	2.24%	1.12%
Fort Wayne	3.04%	1.35%	0.98%	2.62%	0.54%
Greenfield	1.15%	2.09%	13.00%	2.54%	1.98%
LaPorte	2.00%	1.99%	0.73%	-1.95%	4.36%
Seymour	0.20%	2.64%	3.34%	0.08%	0.47%
Vincennes	2.76%	0.41%	8.84%	1.47%	2.61%

Figure 5.7 Variation of net overrun on soil-related items as a percentage of the total construction cost across six districts between 2003–2007

typical low costs of maintenance projects, there were only a few maintenance projects in the 300 contracts covered in the data set) and (iii) various reason codes assigned to change orders.

In the following sections, we will look at all the useful descriptive statistics describing the relevant data from the chosen contracts. The terms that are used throughout this Chapter are as follows:

1. CO: Change Order
2. Total construction cost or total contract cost: total amount spent, calculated after construction.
3. Cost overrun: amount spent in excess of the estimated cost.
4. Cost underrun: difference of the estimated cost and the amount spent, when the expenditure is less than the estimated cost (expressed as negative).
5. Total change order (CO): the sum of magnitudes of the overrun and underrun in terms of costs.
6. Net overrun: difference of Overruns and Underruns = the net amount spent over the estimated costs (negative if there is a net underrun).
7. Soil-related items: any soil-related item, such as aggregate, backfill, backfill borrow, debris removal, erosion, excavation, geogrids, geotextiles, linear grading, riprap, stone, sub-base, subgrade, tie bars and top soil that are recorded in the change order documents (these can be change orders in any type of work – geotechnical or other - with any of the reason codes listed in INDOT's "Policy for Construction Contract Change Orders").
8. Change orders associated with soil-related items: all change orders recorded, involving soil-related items, as described in point 7.
9. Geotechnical reason codes: these are geotechnical reason Codes 108 – Errors and Omissions: Soils Related; 206 – Constructability Issues: Soils Related; and 405 – Changed Field Conditions: Soils Related; as described in INDOT's "Policy for Construction Contract Change Orders.").
10. Geotechnical change orders (geo CO): change orders that have geotechnical reason codes.

As it will be explained in detail later, the data in Section 5.3 contains the change orders associated with soil-related items (which may not be related to geotechnical work). These change orders may not be due to geotechnical reasons. For example, due to a scope change on a particular contract, some additional pavement may have to be constructed. This may require subgrade treatment at the concerned location, where no treatment had been planned for originally. Though the change orders associated with this additional work will involve soil-related items such as aggregate, the change orders would not have occurred due to geotechnical reasons. On the other hand, Section 5.4 contains the geotechnical change order information – change orders with geotechnical reason codes (reason codes **108, 206, 405**). Again, note that all the data presented in this Chapter is only for the top ten contracts (in terms of total construction cost)of six districts in IN for the period of 2003–2007.

5.2. Contract Costs

From the literature review performed for this study, we know that the contract cost is an influential factor in

TABLE 5.2
Variation of total CO and CO in soil-related items

		District (amounts in thousands of dollars)						
Category	Year	Crawford-sville	Fort Wayne	Green-field	LaPorte	Sey-mour	Vincen-nes	Average
Total Change Order Cost	2003	1,301	4,233	8,744	4,993	Seymour	8,166	5,135
	2004	1,375	2,653	9,293	3,288	3,377	6,325	4,965
	2005	3,485	2,478	25,110	7,522	6,855	8,574	8,858
	2006	2,590	5,790	9,132	1,224	5,979	6,532	4,481
	2007	3,338	1,521	7,764	8,597	1,620	13,293	6,142
Net Overrun of Soil-related Items	2003	74	869	926	813	129	1,162	640
	2004	336	374	2,195	737	2,090	616	973
	2005	117	381	11,939	521	1,833	3,414	3,006
	2006	693	1,933	2,382	(346)	11	1,844	887
	2007	280	92	1,228	2,066	173	4,732	1,417
Underrun	2003	−72	−182	−166	−280	677	−65	−225
	2004	−19	−114	−409	−253	−581	−254	−213
	2005	−126	−115	−8	−170	−229	−84	−142
	2006	−109	−183	−52	−466	−350	−599	−262
	2007	−648	−226	0	−249	−161	−34	−235
Overrun	2003	146	1,051	1,092	1,094	−252	1,097	865
	2004	355	489	2,604	990	710	361	1,186
	2005	244	496	11,947	690	2,319	3,330	3,148
	2006	802	2,116	2,434	120	2,183	1,245	1,148
	2007	−928	317	1,228	2,315	172	4,698	1,342
% of CO in Soil-related Items out of Total Change Orders	2003	16.82%	29.12%	14.39%	27.52%	38.25%	14.23%	21.22%
	2004	27.19%	22.72%	32.42%	37.81%	37.17%	9.73%	28.18%
	2005	15.92%	24.64%	47.61%	11.43%	42.36%	39.82%	37.49%
	2006	35.17%	39.72%	27.22%	47.87%	20.54%	28.23%	31.46%
	2007	56.05%	35.69%	15.82%	29.83%	28.91%	35.60%	31.52%

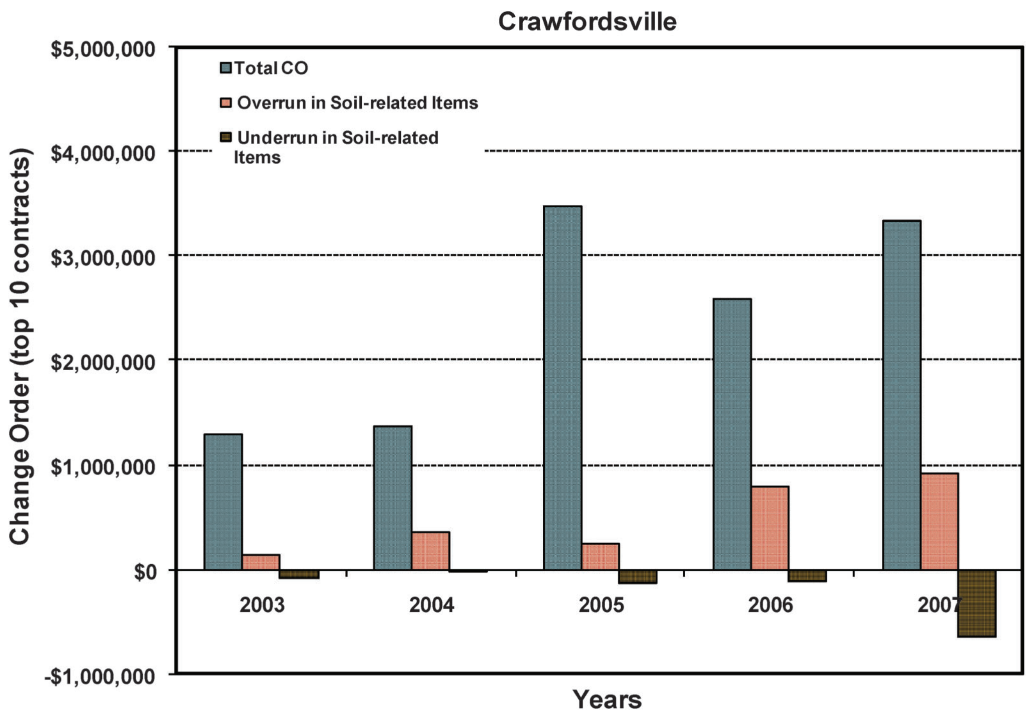


Figure 5.8 Total change orders, cost overruns and underruns for 2003–2007: Crawfordsville.

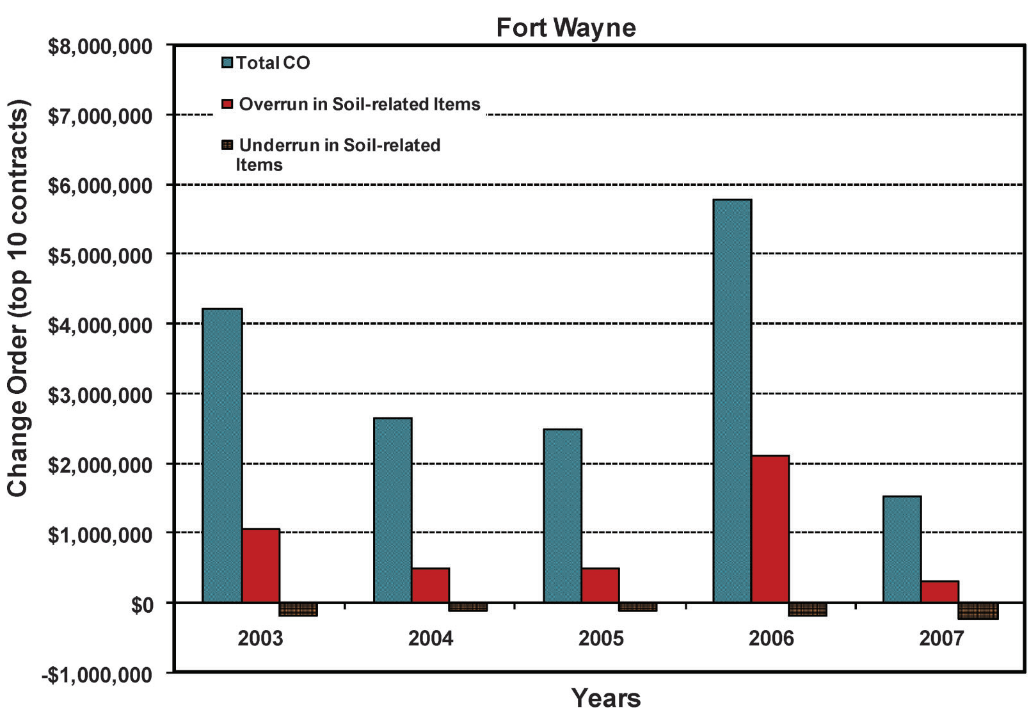


Figure 5.9 Total change orders, cost overruns and underruns for 2003–2007: Fort Wayne

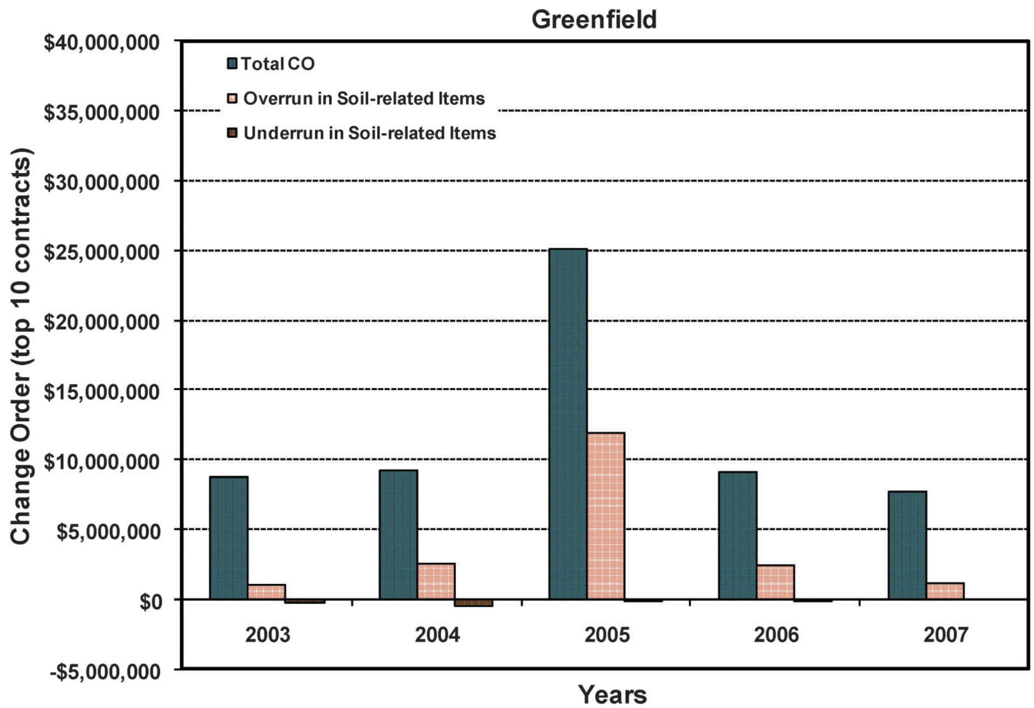


Figure 5.10 Total change orders, cost overruns and underruns for 2003–2007: Greenfield

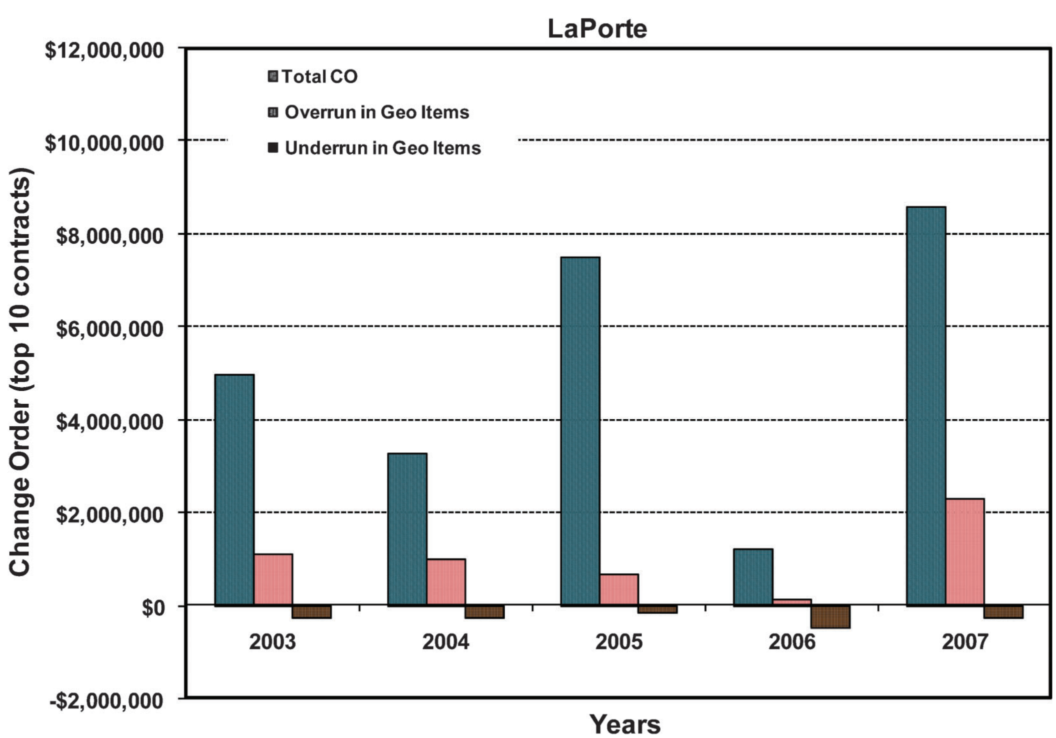


Figure 5.11 Total change orders, cost overruns and underruns for 2003–2007: LaPorte

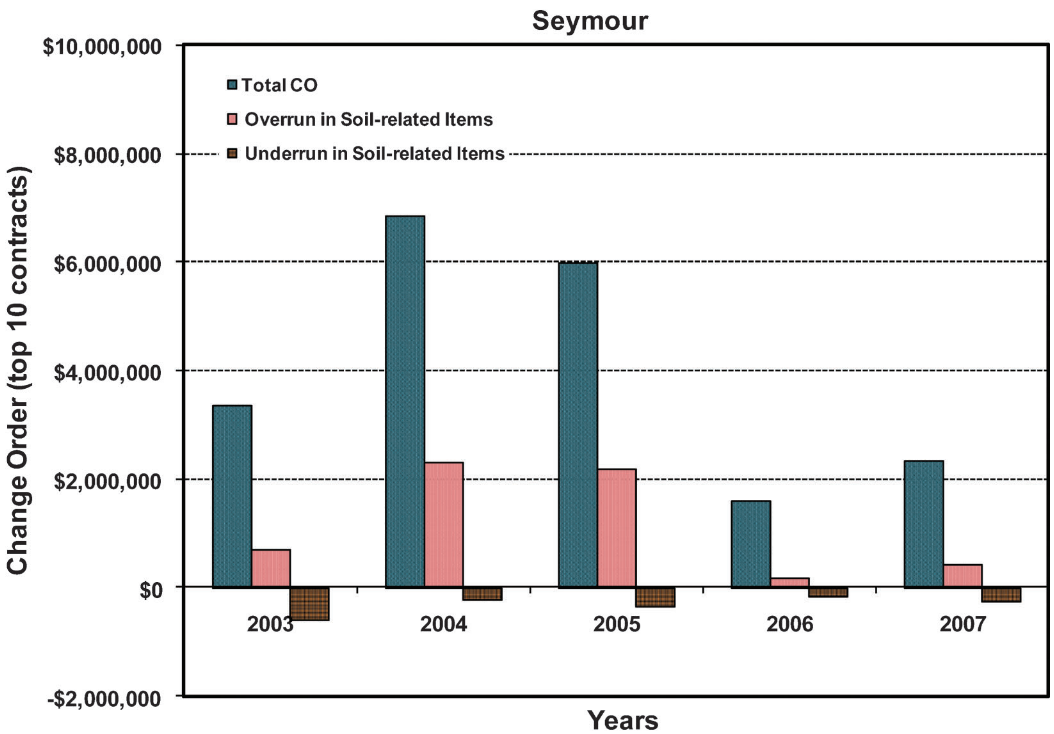


Figure 5.12 Total change orders, cost overruns and underruns for 2003–2007: Seymour

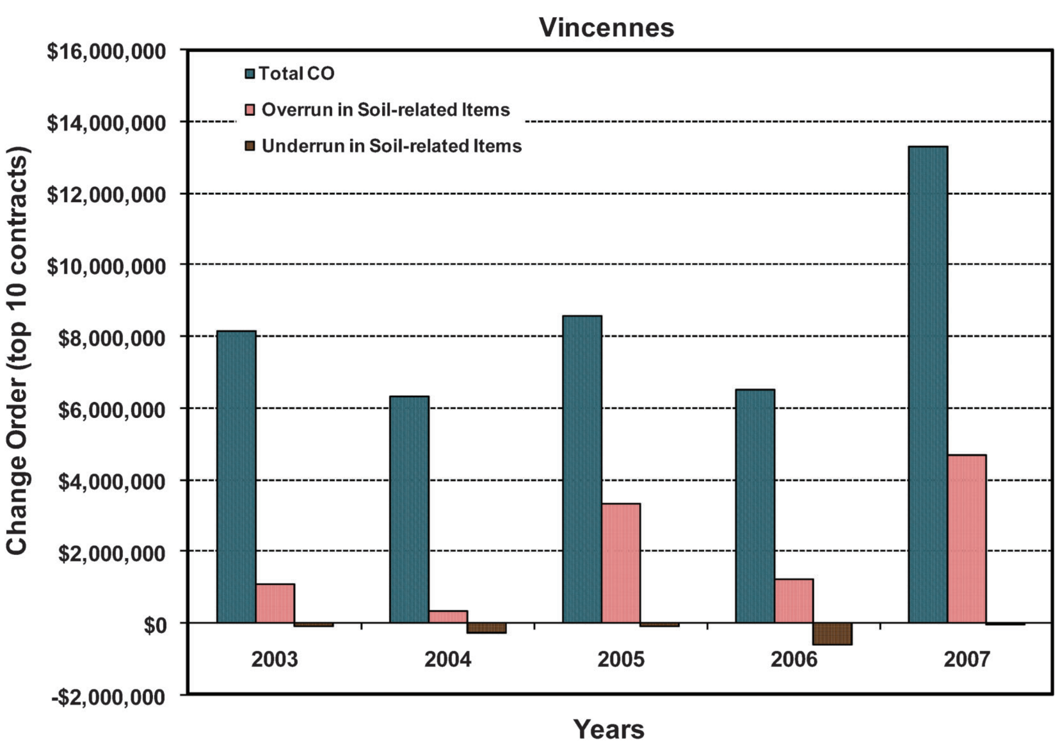


Figure 5.13 Total change orders, cost overruns and underruns for 2003–2007: Vincennes

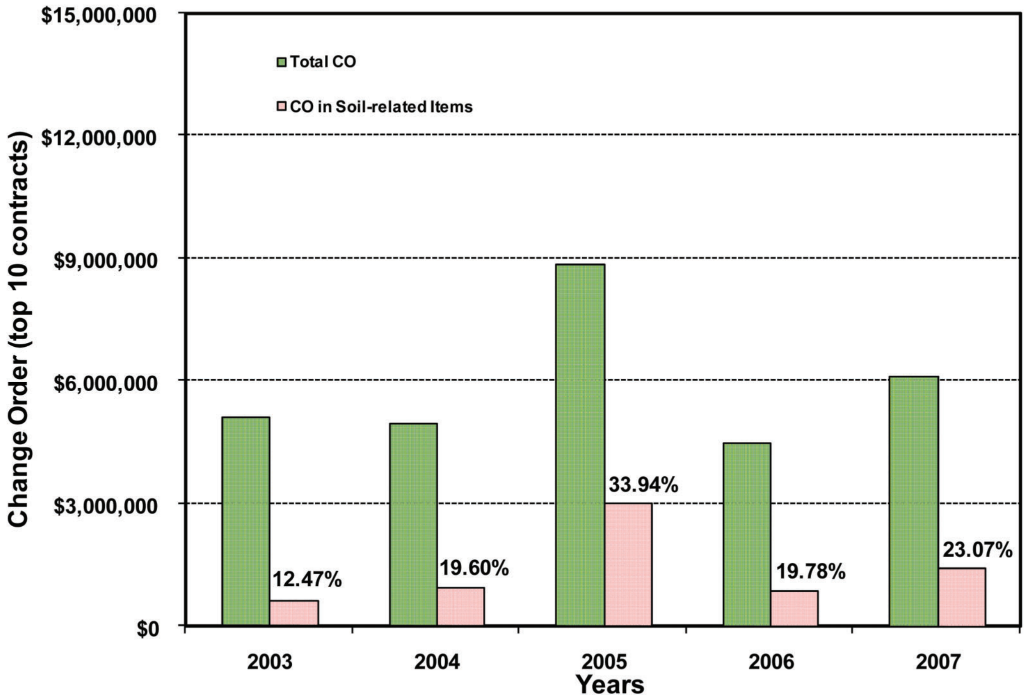


Figure 5.14 Average variation of total change orders and change orders in soil-related items in all six districts of Indiana

TABLE 5.3
Distribution of contracts across percentage ranges of change orders associated with soil-related items with respect to the total change order amounts

Percentage of CO in Soil-related Items	Number of Contracts – District wise						
	Crawfordsville	Fort Wayne	Greenfield	LaPorte	Seymour	Vincennes	Average
0–20%	23	22	23	24	27	37	26.00
20–40%	11	17	14	9	7	5	10.50
40–60%	6	6	3	12	7	3	6.17
60–80%	7	3	6	3	5	3	4.50
80–100%	3	2	4	2	4	2	2.83

TABLE 5.4
Distribution of contracts in ranges of overruns and underruns of soil-related items as a percent of total CO

% Overrun/Underrun of Soil-related Items	Number of Contracts – District-Wise						
	Crawford-sville	Fort Wayne	Greenfield	LaPorte	Seymour	Vincennes	Average
under −75%	2	2	0	5	1	0	1.7
−75 to −50%	2	4	2	3	1	2	2.3
−50 to −25%	7	6	4	7	3	1	4.7
−25 to 0%	7	7	7	8	13	10	8.7
0 to 25%	17	12	13	6	12	17	12.8
25 to 50%	5	7	6	7	4	6	5.8
50 to 75%	3	5	1	5	1	3	3.0
over 75%	7	6	12	8	10	11	9.0

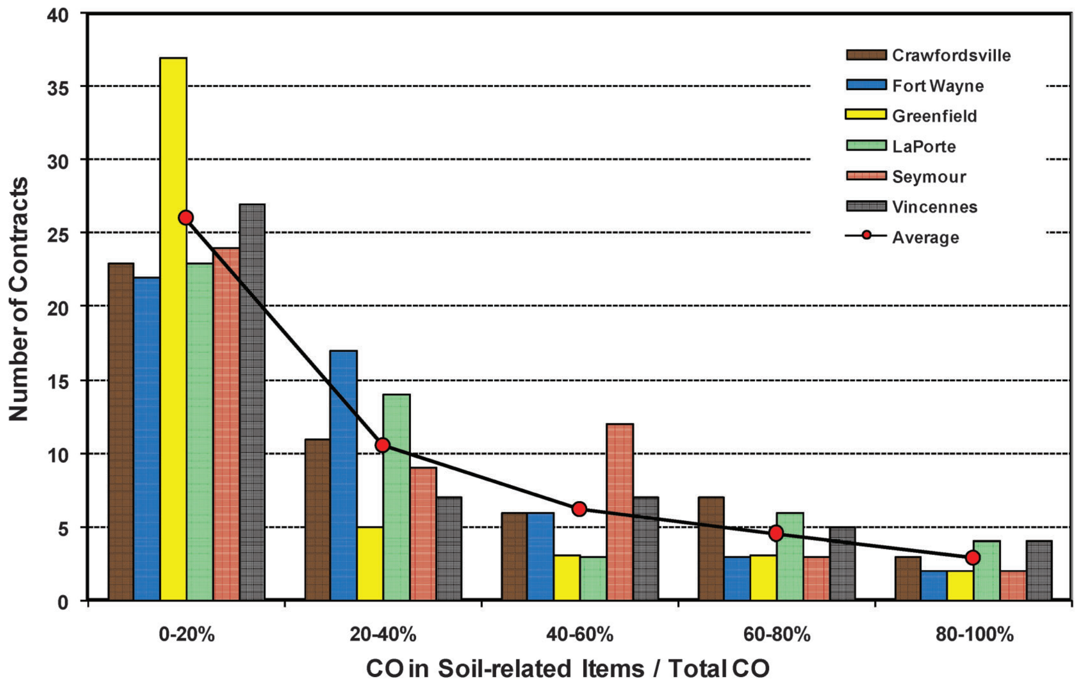


Figure 5.15 Distribution of contracts against amount of change orders in soil-related items expressed as a percentage of total change order amounts

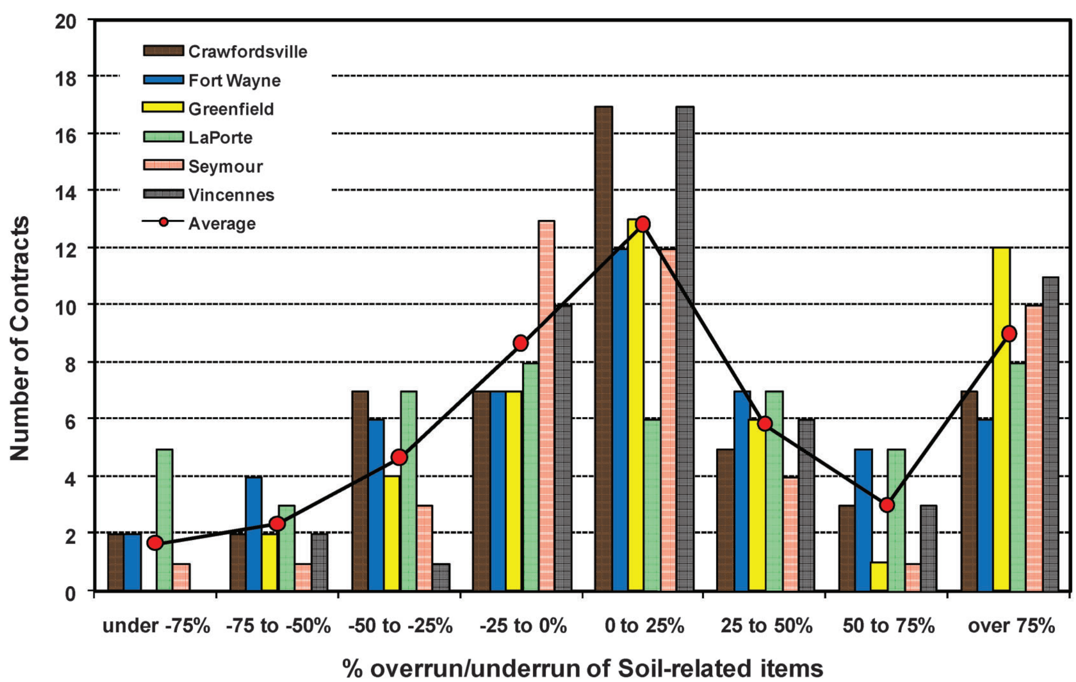


Figure 5.16 Distribution of contracts in ranges of overrun/underrun in soil-related items as a percent of total CO across six districts: 2003 to 2007

TABLE 5.5
Average amounts of overrun/underrun associated with ranges of overrun/underrun of soil-related items as a percent of total CO

Percentage of Overrun/Underrun in Soil-related Items	Average Amounts in Dollars
under −75%	−$78,833.59
−75 to −50%	−$43,283.70
−50 to −25%	−$67,971.93
−25 to 0%	−$143,182.99
0 to 25%	$349,759.79
25 to 50%	$617,149.59
50 to 75%	$205,388.99
over 75%	$779,246.06

the eventual amount of change orders. According to some of the studies presented in the literature review in Chapter 2, the greater the total construction cost, the greater the number of change orders is. Hence, the decision to look at the distribution of annual contract costs amidst the six districts between the years 2003 and 2007. Also, since we are trying to examine the circumstances and causes of geotechnical change orders at INDOT, the amounts spent annually on soil-related items on all the contracts are also important information. It is reasonable to assume that if the total cost for soil-related items is higher, then the number of geotechnical change orders is also higher. Table 5.1 shows the variation of annual construction costs and annual cost of soil-related items for the top ten contracts in each of the six districts during the period 2003 to 2007. Figures 5.1 to 5.6 represent this variation through bar graphs for each of the six districts. Along with the annual construction costs and the annual cost for soil-related items, the cost of soil-related items is also shown as a percentage of the total construction cost in order to portray the relative standing between the two quantities. From these figures, it is seen that the cost of soil-related items understandably increases with increases in total contract cost in many cases. Over the five-year period, Greenfield had the maximum construction costs on all years, except in 2007 when Vincennes topped with a total construction cost of $178,915,172.43 from the top ten contracts. This also happens to be the maximum cost spent in a single year from the top ten contracts from any of the districts in any year; the corresponding cost for soil-related items is $33,753,753.50, which is 18.87% of the total construction cost. The next highest annual contract amount is $104,862,893.04 spent in Greenfield in the top ten contracts from 2006. The corresponding amount spent on soil-related items for this year is $13,631,394.58, making up for 13.00% of the total construction cost in the top ten contracts of that year.

5.3. Change orders associated with soil-related items

In this section, we look at the change order data from the top ten contracts in all six districts between the years 2003 and 2007. Figure 5.7 shows the net overrun of soil-related items as a percentage of the total constructions costs. The net overrun is calculated by subtracting the overruns from the underruns. The net overruns are not alarmingly high for any of the

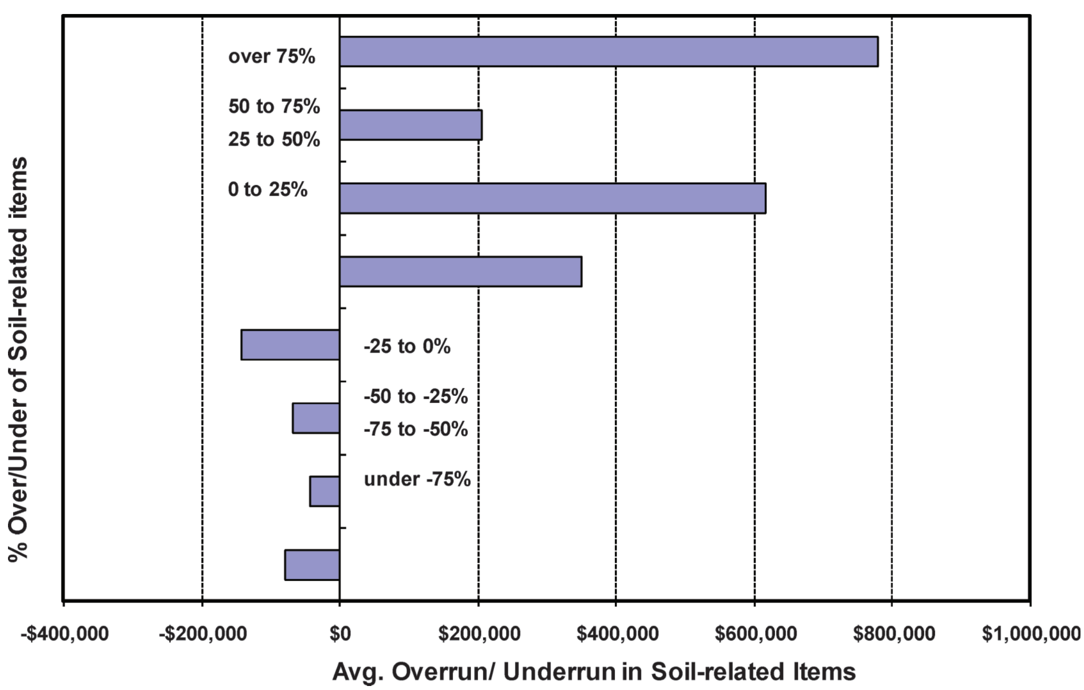


Figure 5.17 Average overrun/underrun amounts associated with ranges of change orders in soil-related items as a percent of total change orders

TABLE 5.6
Number of contracts vs. Changes in soil-related items per contract

Number of Changes in Soil-related Items/ Contract	Number of Contracts
1	25
2	21
3	19
4	20
5	19
6	21
7	21
8	18
9	11
10	13
11	12
12	7
13	9
14	18
15	12
16	5
17	8
18	4
19	6
20	4
21	4
22	3
23	2
24	5
25	2
26	2
27	2
28	1
29	1
30	0
31	1
35	1
36	1
42	1
47	1

districts, except for a relatively high 13% net overrun in Greenfield in the year 2005 which is accompanied by negligible underruns. In all the districts, greater cost overrun than cost underrun in soil-related items is seen in most years, the exceptions being LaPorte in 2006 and Crawfordsville in 2007, as indicated by their negative percentages of net overrun. However, these can be seen as acceptable considering that the costs for any type of construction work rarely runs under or parallel to the expected costs.

Table 5.2 and Figures 5.8 to 5.14 show the variation of the amount of change orders in soil-related items along with the total change order amounts in each district between the years of 2003 and 2007. The change orders associated with soil-related items are split into cost overruns and cost underruns. Considering that we are looking at the change orders associated with all the soil-related items, it is not surprising that these count on for 21.77% of the total change orders for all the 300 contracts. Later in this Chapter, we will look at only the geotechnical change orders (with geotechnical reason codes**108, 206, 405**), which should give a better and more detailed assessment of the change orders related to geotechnical work.

Fig.5.14 shows the variation of average total change orders and average change orders (net overrun) in soil-related items for all the six districts of Indiana between the years 2003 and 2007.

Table 5.3 and Fig. 5.15 describe the distribution of the number of contracts across specific ranges of percentages of amount of change orders (overrun + underrun) associated with soil-related items in each district in each year. The change order amounts are calculated by adding the magnitudes of overrun and underrun costs on each contract; these are further expressed as a percentage of the total change order amounts in each contract. One has to note that these percentages are different from the percentages of net overruns in soil-related items that were shown in Fig. 5.2, where the net overruns were the sum of the overruns and the underruns that were finally expressed as a percentage of the total construction cost.

We also looked at the ranges of overruns and underruns in soil-related items that have occurred in the 300 contracts in each of the six districts between 2003 and 2007. Table 5.4 displays this data. Figure 5.16 presents this distribution in terms of bar graphs. It can be seen that the maximum number of contracts lie in the 0 to 25% range of cost overruns in soil-related items, the amounts being calculated as a percentage of the total change order amounts. This trend is observed in almost all the districts.

Table 5.5 gives the average amounts associated with each percentage range of overruns or underruns in soil-

TABLE 5.7
Number of changes in soil-related items across districts in 2003–2007

	Number of Contracts – District wise							
Years	Crawford-sville	Fort Wayne	Greenfield	LaPorte	Seymour	Vincennes	Total	Average
2003	26	96	122	110	144	122	620	103.33
2004	61	67	128	94	84	116	550	91.67
2005	86	96	100	94	118	107	601	100.17
2006	85	121	97	68	94	112	577	96.17
2007	80	86	72	90	68	170	566	94.33

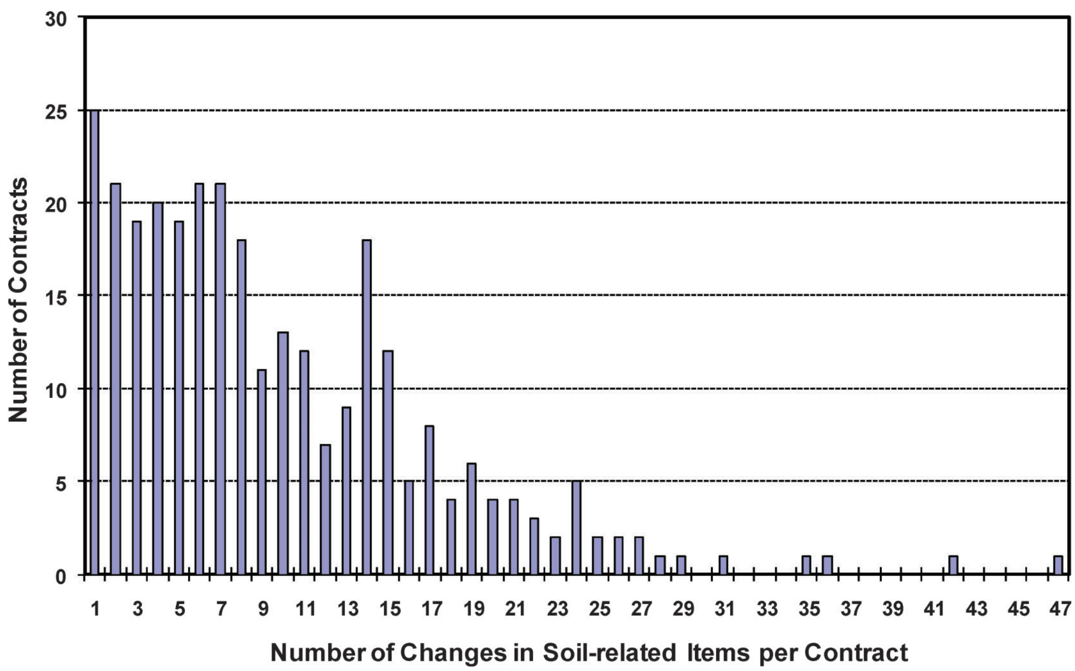


Figure 5.18 Number of contracts vs. Number of changes in soil-related items per contract

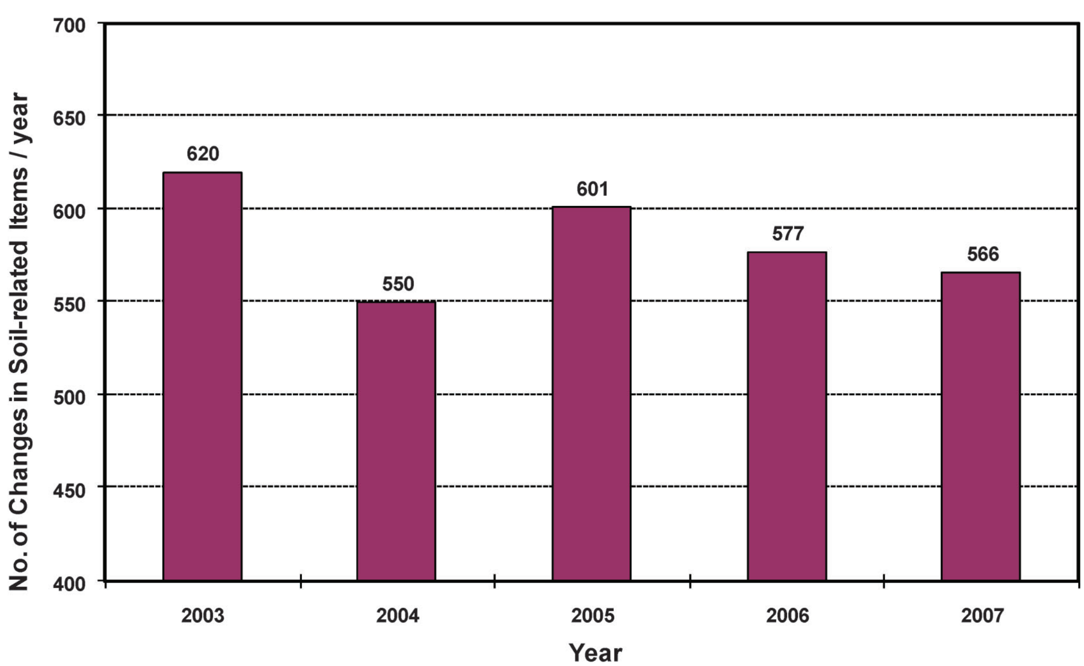


Figure 5.19 Variation of number of changes in soil-related items between 2003 and 2007

TABLE 5.8
Data from Road Contracts in Indiana

Category	Year	District (amounts are in thousands of dollars)						
		Crawford-Sville	Fort Wayne	Green-field	LaPorte	Seymour	Vince-Nnes	Average
Total Construc-tion Cost	2003	838	21368	74040	19049	63895	5748	30823
	2004	4270	14814	94912	23793	74269	19258	38553
	2005	22669	28539	90398	38290	49451	26712	42676
	2006	25138	59775	86721	3323	5582	32481	35503
	2007	17093	7703	60289	25849	28392	175881	52535
Total Cost of Soil-related Items	2003	18	2843	10504	3578	13403	1335	5280
	2004	285	1842	12995	3489	18309	4665	6931
	2005	3090	5583	28022	5714	11124	7314	10141
	2006	6165	9950	16310	321	1264	9444	7242
	2007	2600	2282	8413	4187	2694	33651	8971
Total CO	2003	272	2190	7925	2625	3165	1136	2885
	2004	415	1276	7972	2160	6276	4700	3800
	2005	2698	1405	24786	2944	5399	6873	7351
	2006	1851	4792	7950	321	848	4636	3400
	2007	2580	884	7315	6649	1642	12594	5277
CO in Soil-related Items	2003	10	1023	1102	389	1153	495	695
	2004	118	305	2989	853	2336	440	1173
	2005	396	387	11950	484	2515	3115	3141
	2006	1017	2134	2348	163	148	1353	1194
	2007	561	320	1190	2081	537	4710	1566
% CO in Soil-related Items out Of Total CO	2003	3.84%	46.74%	13.91%	14.80%	36.42%	43.61%	24.10%
	2004	28.41%	23.88%	37.49%	39.51%	37.22%	9.37%	30.88%
	2005	14.67%	27.52%	48.21%	16.44%	46.59%	45.33%	42.73%
	2006	54.94%	44.52%	29.53%	50.72%	17.46%	29.18%	35.11%
	2007	21.73%	36.17%	16.27%	31.29%	32.69%	37.40%	29.68%
Number of contracts	2003	1	5	8	3	9	3	5
	2004	3	4	7	5	6	6	5
	2005	5	4	9	4	7	4	6
	2006	6	5	7	3	4	4	5
	2007	5	5	8	3	3	9	6

related items, calculated as a percentage of the total change order amounts. Figure 5.17 presents this data.

We now examine the variation of the number of changes in soil-related items that occurred in the 300 contracts. The contracts are counted separately based on the number of changes in soil-related items in each of these contracts. One or more changes to soil-related items may belong to the same change order. For example, a single change order may have had changes in aggregate, riprap and geogrids, and these changes are counted as three changes in soil-related items even though they belong to the same change order. These data are presented in Table 5.6 and in Figure. 5.18. It can be seen that the maximum number of contracts (25) have just one change in soil-related items. Also, there are 21 contracts, each with two, six and seven changes in soil-related items per contract. Most of the occurrences are populated in the less than seven changes in soil-related items per contract range.

Table 5.7 shows the variation of the number of changes in soil-related items across the six districts between the years 2003 and 2007. The maximum number of changes associated with soil-related items was 170 in Vincennes in the year 2007. On average, there were about 583 changes per year in all the six districts put together. Figure 5.19 shows the variation of number of changes per year in all the six districts put together. The year of 2003 had a maximum of 620 changes associated with soil-related items.

5.3.1. Contract Types

Out of the 300 contracts on the data set, there were 155 road contracts, 96 resurfacing contracts, 44 bridge contracts and 5 maintenance contracts. From the geotechnical office at INDOT, we learnt that they rarely have anything to do with change orders on resurfacing projects. This is also reflected by the data in the fact that even though the resurfacing contracts have change orders in soil-related items, they rarely have change orders with geotechnical reason codes. The data for the geotechnical change orders will be presented in sections later on this Chapter. In this section, we will continue to examine the data from change orders associated with soil-related items, looking at their variation with the four contract types – Road (R) Resurfacing (RS), Bridge (B) and Maintenance (M). Since only the top ten contracts of every year were

TABLE 5.9
Data from Resurfacing contracts in Indiana.

Category	Year	District (amounts are in thousands of dollars)						
		Crawford-sville	Fort Wayne	Green-Field	LaPorte	Seymour	Vincennes	Average
Total Constru-ction Cost	2003	7337	4402	0	5844	0	3918	3583
	2004	8267	12857	3015	7001	4425	4005	6595
	2005	5242	10160	1472	14072	5458	8555	7493
	2006	2300	14053	7093	10419	4899	10977	8290
	2007	6153	9336	1446	10036	3092	3034	5516
Total Cost of Soil-related Items	2003	296	272	0	188	0	404	193
	2004	545	630	34	371	220	175	329
	2005	192	292	8	607	179	983	377
	2006	13	587	265	986	186	1060	516
	2007	416	406	65	438	56	102	247
Total CO	2003	829	853	0	679	0	570	489
	2004	573	1376	571	626	430	1394	828
	2005	372	1074	325	3486	580	1533	1228
	2006	117	997	1182	253	434	1594	763
	2007	502	638	190	1271	380	699	613
CO in Soil-related Items	2003	98	162	0	160	0	203	104
	2004	112	298	18	221	146	115	152
	2005	64	224	5	195	17	249	126
	2006	12	166	138	202	40	491	175
	2007	284	223	37	187	49	22	134
% CO in Soil-related Items out Of Total CO	2003	11.86%	18.94%	-	23.58%	-	35.57%	21.24%
	2004	19.53%	21.64%	3.15%	35.30%	33.89%	8.24%	18.29%
	2005	17.23%	20.86%	1.55%	5.60%	2.97%	16.27%	10.25%
	2006	10.39%	16.65%	11.66%	79.63%	9.17%	30.81%	22.91%
	2007	56.60%	35.03%	19.35%	14.75%	12.81%	3.09%	21.79%
Number of contracts	2003	7	3	0	3	-	2	3
	2004	4	6	1	3	3	3	3
	2005	3	6	1	3	3	5	4
	2006	1	5	3	3	4	5	4
	2007	3	5	1	4	5	1	3

chosen from every district, the data set included a very low number of maintenance contracts, considering that maintenance contracts typically don't have large budgets.

Table 5.8 shows the construction cost and change order data for all the 155 road projects from the six districts. Table 5.9 shows the construction cost and change order data for all the 96 resurfacing contracts. Table 5.10 shows the construction cost and change order data for the 44 bridge contracts that were part of the data set. Table 5.11 shows the construction cost and the change order data from the five maintenance contracts in the data set. From this data, it is clear which types of contracts undergo maximum change orders in general, particularly for change orders associated with soil-related items.

Figure 5.20 clearly shows that road projects dominate in number over the five years. Fig.5.21 shows the contribution of each contract type to the average construction cost over the five year period between 2003 and 2007 from all the six districts. Again, it is seen that the maximum construction costs are concentrated in road contracts. This is expected as well considering the length of road projects. This reinforces what was already evident from the fact that the top 300 contracts in terms of construction costs contained 155 road contracts. Fig. 5.22 shows the variation of the amount of change orders associated with soil-related items for every contract type between the years of 2003 and 2007. As one would anticipate, road projects have the maximum amount of change orders in the category of soil-related items. The year of 2005, saw a large number of change orders associated with soil-related items as the six districts had many expensive road contracts completed in that year.

5.3.2. COs in Soil-related Items Classified Based on Reason Codes

In Chapter 4, we looked at all the reason codes for change orders. Based on these reason codes, the data was classified such that the reason codes that occurred frequently could be identified. This was done to help in determining problematic issues that cause changes in soil-related items. In this section, we look at the changes that took place for various soil-related items. Changes to various soil-related items may have taken place as part of the same change order, however here they were classified as separate changes on individual items.

TABLE 5.10
Data from Bridge Contracts in Indiana

		District (amounts are in thousands of dollars)						
Category	Year	Crawford-sville	Fort Wayne	Green-field	LaPorte	Seymour	Vincennes	Average
Total Constru-ction Cost	2003	276	2826	6171	15318	1247	27763	8934
	2004	3575	0	6936	6271	0	3019	3300
	2005	1538	0	0	6646	0	1453	1606
	2006	2824	0	0	4010	3930	544	1885
	2007	1793	0	0	11447	1993	0	2539
Total Cost of Soil-related Items	2003	143	372	437	1863	186	2875	979
	2004	679	0	602	601	0	192	346
	2005	201	0	0	335	0	314	142
	2006	502	0	0	453	556	7	253
	2007	427	0	0	784	682	0	315
Total CO	2003	105	1190	818	1387	212	6460	1695
	2004	387	0	750	502	0	231	312
	2005	414	0	0	559	0	168	190
	2006	311	0	0	650	339	303	267
	2007	256	0	0	676	139	0	179
CO in Soil-related Items	2003	15	47	156	705	139	464	254
	2004	188	0	6	169	0	61	71
	2005	126	0	0	158	0	49	56
	2006	150	0	0	222	145	0	86
	2007	108	0	0	296	85	0	82
% CO in Soil-related Items out Of Total CO	2003	14.78%	3.97%	19.05%	50.84%	65.50%	7.18%	15.01%
	2004	48.52%	-	0.78%	33.62%	-	26.15%	22.62%
	2005	30.37%	-	-	28.35%	-	29.12%	29.20%
	2006	48.21%	-	-	34.09%	42.80%	0.02%	32.23%
	2007	42.22%	-	-	43.80%	61.25%	-	45.69%
Number of Contracts	2003	1	2	2	4	1	5	3
	2004	3	0	2	2	0	1	1
	2005	2	0	0	2	0	1	1
	2006	2	0	0	4	2	1	2
	2007	2	0	0	3	2	0	1

Recall the example already mentioned - a single change order may have had changes in aggregate, riprap and geogrids (these changes were counted as three changes) in soil-related items even though these changes belonged to the same change order. Table 5.12 shows the frequency of occurrence for each of the major classification of reason codes associated with changes in soil-related items in each of the six districts. Greenfield has the maximum number of changes with respect to soil-related items. The major classification includes all the reason codes that fall in hundreds. For example, all the reason codes that fall in the 100's (101, 102… and so on) belong to "Errors and Omissions" and classify into one major division. The reason codes and their explanation were listed in Chapter 4. Figure 5.23 shows the major classifications and their frequencies in all six districts together. These are reason code occurrences for changes in soil-related items. We can see that constructability issues were responsible for 831 changes in soil-related items. This was the maximum, ahead of the 637 changes due to "Errors and Omissions".

In order to further narrow down on the frequent reason codes, the major classification of reason codes was broken down to individual reason codes for every

TABLE 5.11
Data from Maintenance Contracts from Indiana

Year	Total const. cost	Total soil-related item	Total CO	CO in soil-related item	% of Geo CO	No. of contracts
2003	$22,000.00	$21,716.67	$15,750.00	$15,750.00	100.00%	1
2004	$0.00	$0.00	$0.00	$0.00	-	0
2005	$0.00	$0.00	$0.00	$0.00	-	0
2006	$105,009.94	$198.33	$51,809.94	$128.33	0.25%	1
2007	$65,178.06	$220.00	$43,246.07	$170.00	0.39%	1

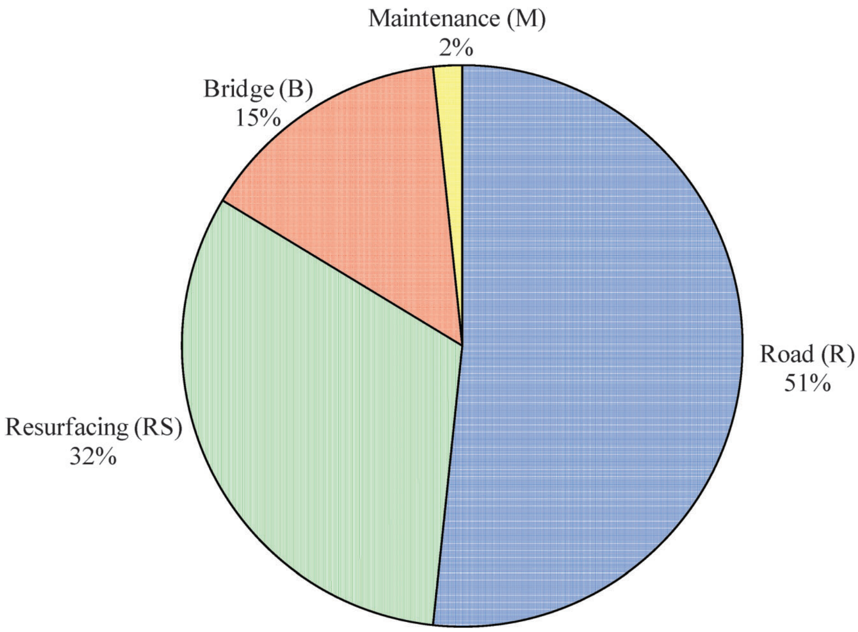


Figure 5.20 Distribution of the number of contracts with project types in the six districts of Indiana between 2003 and 2007

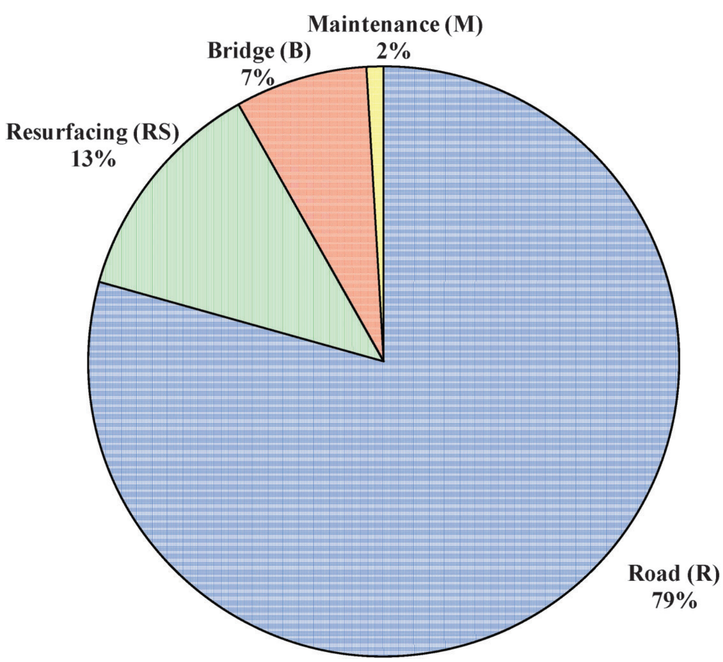


Figure 5.21 Distribution of average construction costs of each contract type

TABLE 5.12
Number of changes in soil-related items vs. Reason codes

	Number of Contracts – District wise					
Major Classification of Reason Code	Crawford-Sville	Fort Wayne	Greenfield	LaPorte	Seymour	Vincennes
Errors and Omissions -100's	44	47	279	88	77	102
Constructability- 200's	85	133	176	122	155	160
Scope Changes- 300's	22	39	53	32	52	73
Changed Field Conditions - 400's	20	32	58	50	79	50
Incentive / Disincentive – 600's	0	0	0	0	4	0
Standard / Spec. Change – 700's	0	2	2	0	1	2
Total	171	253	568	292	368	387

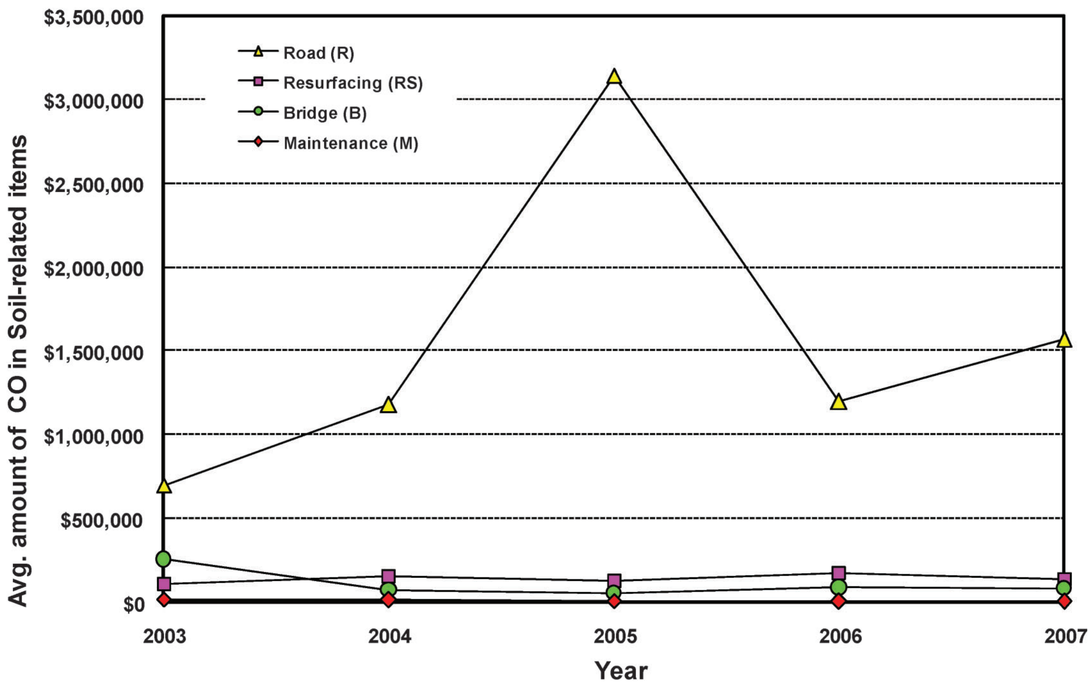


Figure 5.22 Variation of average annual construction costs from all districts among different contract types – 2003 to 2007

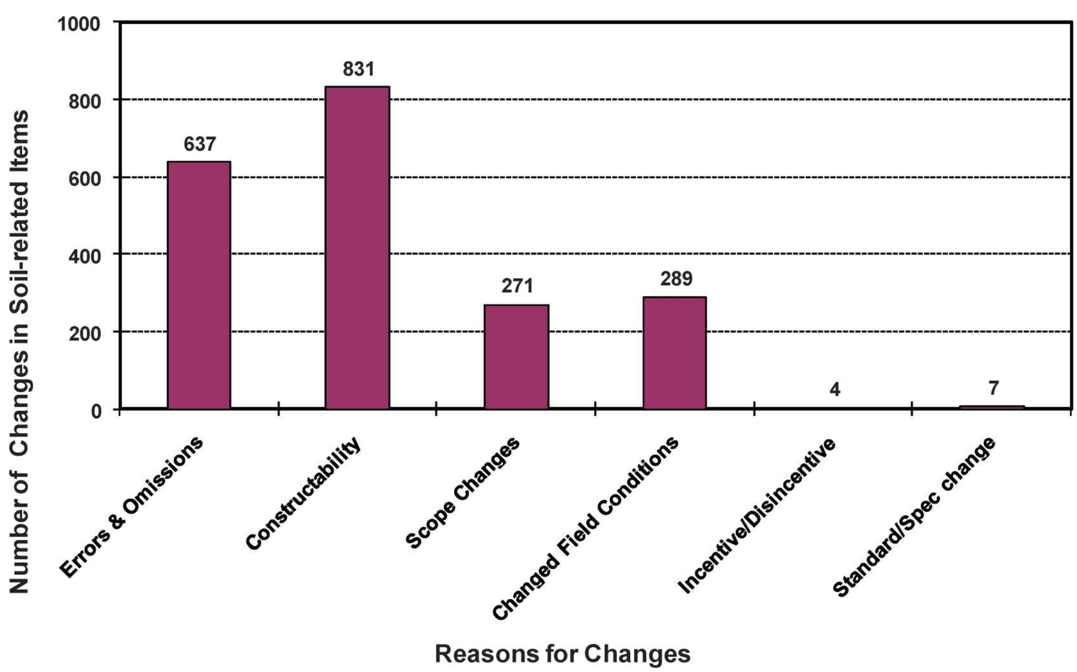


Figure 5.23 Number of changes in soil-related items vs. Reasons for changes

TABLE 5.13
Frequency of reason codes for changes in soil-related items

Prominent Reason Codes	Number of Contracts – District wise						Total
	Crawford-sville	Fort Wayne	Greenfield	LaPorte	Seymour	Vincennes	
101	4	1	19	4	5	10	43
102	26	31	122	40	45	51	315
106	9	13	134	41	22	23	242
201	40	56	99	49	51	57	352
202	6	17	13	17	26	20	99
203	1	6	11	2	2	12	34
204	2	9	13	10	9	3	46
206	34	39	32	30	37	60	232
209	-	2	4	-	23	1	30
302	1	1	12	2	21	11	48
303	-	20	6	3	-	3	32
305	2	1	5	4	5	9	26
306	2	2	10	5	6	16	41
308	17	14	12	16	12	5	76
309	-	-	2	2	-	28	32
401	9	17	29	34	49	28	166
405	7	10	17	13	28	13	88

one of the changes associated with soil-related items. The most frequent reason codes – those that occurred more than 20 times – are shown in Table 5.13. Fig. 5.24 shows this variation using bar graphs. It can be seen that reason codes 201 – Construction Related Constructability Issues and 102 - Design Related Errors and Omissions - were the most frequent of the reason codes with 352 and 315 occurrences, respectively. Reason codes 106 – Quantities Related Errors and Omissions and 206 – Soils Related Constructability Issues also had more than 200 occurrences each. It is also of importance that reason code 108 – Soils Related Errors and Omissions had less than 20 occurrences (13 to be exact) and hence does not figure in the table or graph containing frequently occurring reason codes.

5.4. Geotechnical Change Orders

In the previous section, we looked at the change orders associated with soil-related items. In this section, we look at the geotechnical change orders – change orders that had geotechnical reason codes (**108, 206, 405**), and that can be assumed to have occurred due to geotechnical reasons. The geotechnical reason codes that were assigned to these change orders were – 108: Errors and Omissions - Soils Related; 206: Constructability – Soils Related; 405 – Changed Field Conditions – Soil Related. The data was broken down to identify these change orders separately, and the corresponding descriptive statistics were prepared. Firstly, we look at the geotechnical change order amounts for each of the six districts in each of the five years between 2003 and 2007. Table 5.14 shows the net overrun in geotechnical change order amounts and their percentages in terms of the total construction cost. It can be seen that, except in LaPorte in 2004, which had an underrun, generally geotechnical change order amounts are overruns. The highest was in 2005 when Greenfield had a net overrun of over eight million due to geotechnical change orders. Otherwise, the percentages seem to be pretty low as far as geotechnical change orders are concerned. It should also be noted in Fig. 5.25, Fig. 5.26 and Fig. 5.27 that there are no bar graphs for the district of Crawfordsville in the year of 2003. This is because the district of Crawfordsville did not experience any geotechnical change orders in 2003. The net overrun amounts due to geotechnical change orders are represented in Figure 5.25 in the form of bar graphs. Figure 5.26 displays the percentage of net overruns due to geotechnical change orders in terms of the total construction cost.

In Fig. 5.25, we looked at the net geotechnical overrun as a percentage of the total construction cost for each year. It is also useful to look at it from the individual contracts' perspective. Table 5.15 and Figure 5.26 show the distribution of contracts among various net geotechnical overrun percentage ranges. It can be seen that almost all of the contracts lie under the ten percent range. In fact, on average a larger number of contracts lie in the 0–1 percent range or the less than zero range, implying a cost underrun due to geotechnical change orders. As mentioned earlier, the district of Crawfordsville had no geotechnical change orders in the year 2003.

Table 5.16 shows the variation of number of contracts with the number of geotechnical change orders per contract for each of the six districts between the years of 2003 and 2007. The data shows that 46 of the 84 contracts that experienced geotechnical change orders had only one geotechnical change order, and 24 contracts had two geotechnical change orders. Hence,

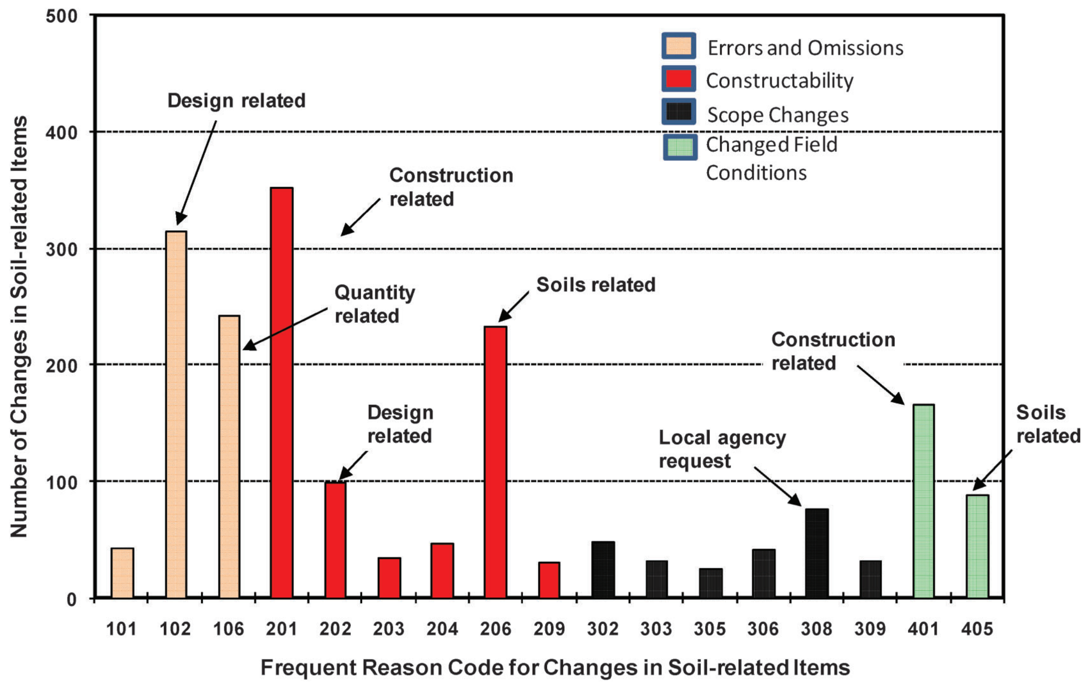


Figure 5.24a Frequent reason codes for changes in soil-related items vs. Number of changes is soil-related Items

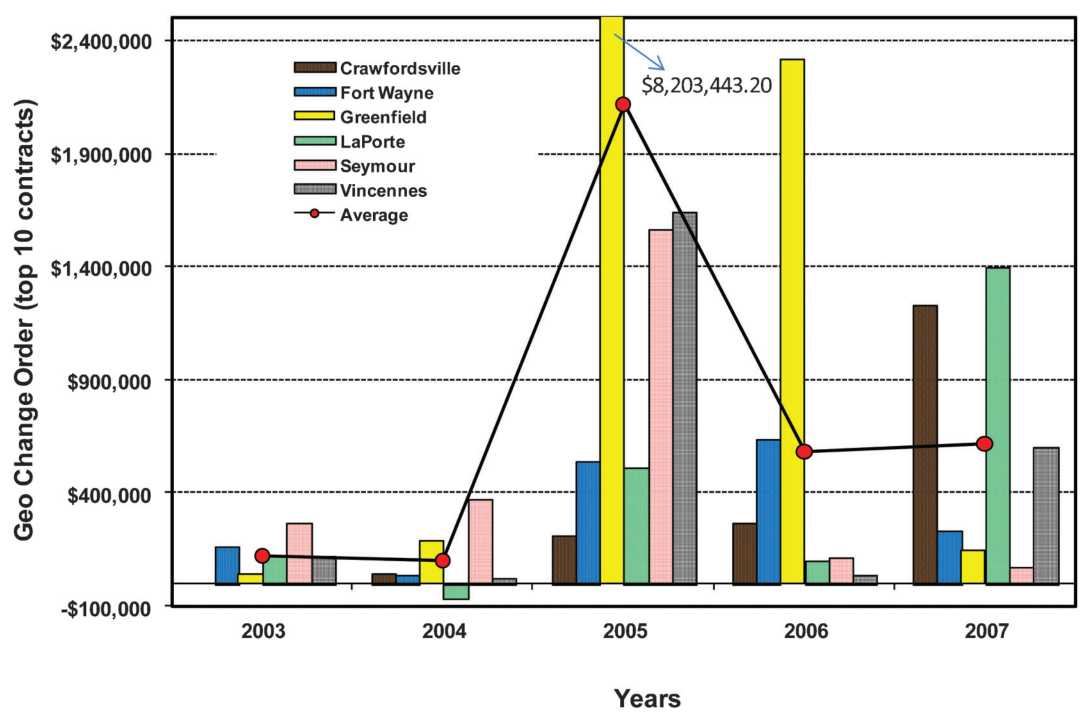


Figure 5.24b Variation of net overrun due to geotechnical change orders in all six districts: 2003–2007

TABLE 5.14
Geotechnical change order data from all six districts

Category	Year	Amounts in thousands of dollars for each district						
		Crawford-sville	Fort Wayne	Green-field	LaPorte	Seymour	Vince-nnes	Average
Net Overrun due to Geotech-nical CO	2003	$0	$164	$43	$120	$270	$126	$121
	2004	$44	$43	$188	$65	$377	$27	$102
	2005	$216	$543	$8,203	$511	$1,566	$1,642	$2,114
	2006	$269	$638	$2,318	$104	$118	$38	$581
	2007	$1,233	$238	$146	$1,401	$75	$602	$616
Geotech. CO as a percentage of Total Constru-ction Cost	2003	0.00%	0.58%	0.05%	0.29%	0.42%	0.34%	0.28%
	2004	0.27%	0.15%	0.18%	−0.18%	0.48%	0.10%	0.21%
	2005	0.73%	1.40%	8.93%	0.72%	2.85%	4.47%	3.92%
	2006	0.87%	0.86%	2.47%	0.59%	0.82%	0.09%	1.27%
	2007	4.92%	1.40%	0.23%	2.96%	0.21%	0.34%	1.01%

even in contracts that undergo change orders with soil-related reason codes, the number of geotechnical change orders is low. Figure 5.27 shows this variation in the form of a simple bar graph.

Table 5.17 and Figure 5.28 show the variation of number of geotechnical change orders for each year between 2003 and 2007. Table 5.17 also shows the district-wise data distribution.

5.4.1. Variation of Geo CO Data with Contract Types

Similar to the change orders associated with soil-related items, here we look at the variation of geotechnical change orders with respect to project types. Resurfacing contracts observed literally no geotechnical change orders, with a meager quantity of about four percent of the total number of contracts that experienced geotechnical change orders. Maintenance contracts, already very few in numbers, had no geotechnical change orders. Out of the 84 contracts that experienced geotechnical change orders, 64 were road contracts, 16 bridge contracts and 4 resurfacing projects. About 41% of the total road contracts (155) experienced geotechnical change orders. About 37% of the total bridge contracts (44) experienced geotechnical change orders. The other contract types in this study's dataset have insignificant number geotechnical change orders. Table 5.18 and Table 5.19 show the net overrun data for geotechnical change orders in road and bridge contracts, respectively.

Figure 5.29 shows the variation of average net overruns due to geotechnical change orders with contract types. Expectedly, road contracts have maximum amounts, with the highest being in 2005, which also had the maximum change orders with respect to soil-related items, as shown previously in Figure 5.21.

In this section, the reason code data for geotechnical change orders is presented. The number of occurrences of the three Soils - related reason codes 108 - Errors and Omissions; 206 – Constructability Issues; 405 - Changed Field Conditions, in each district is shown in Table 5.20. Figure 5.30 reflects the same data. It can be noticed that this is different from the occurrences for these reason code (108, 206 and 405) presented in Section 5.3.2, where the total number of soil-related items that underwent changes with these reasons were 333. Here, we are looking at only the number of change orders that were associated these reason codes, 158 of them, and not looking at the changes to individual items. It is observed that geotechnical constructability issues cause maximum number of geotechnical change orders. Changed field conditions also cause a considerable number of geotechnical change orders. Errors and Omissions related to soils is a very rare reason for change orders in geotechnical work.

5.5. Summary

In this chapter, the data from the top ten contracts in terms of total construction costs per year for each

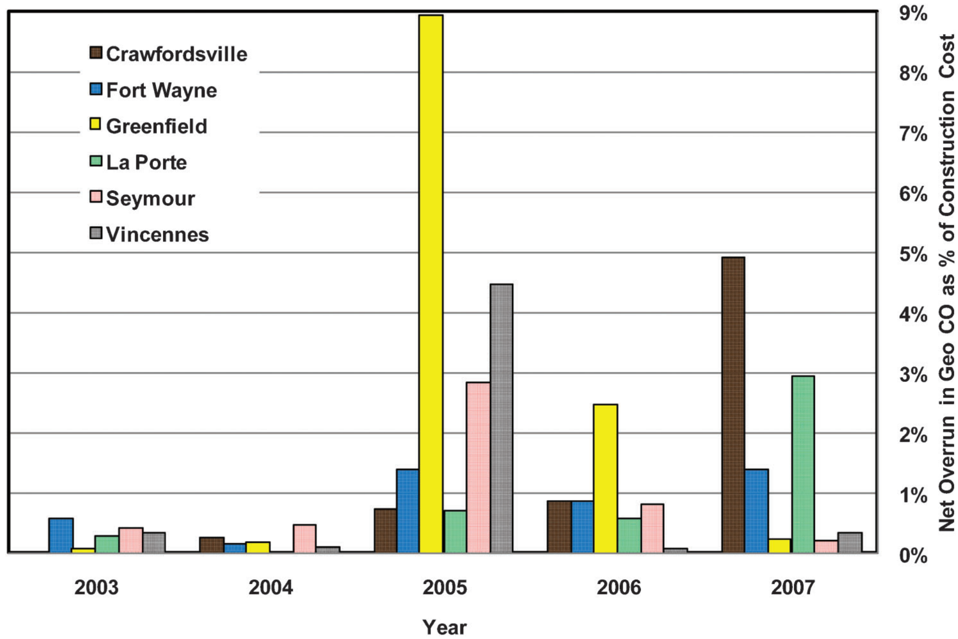


Figure 5.25 Net overrun in geo CO vs. years in all six districts of Indiana

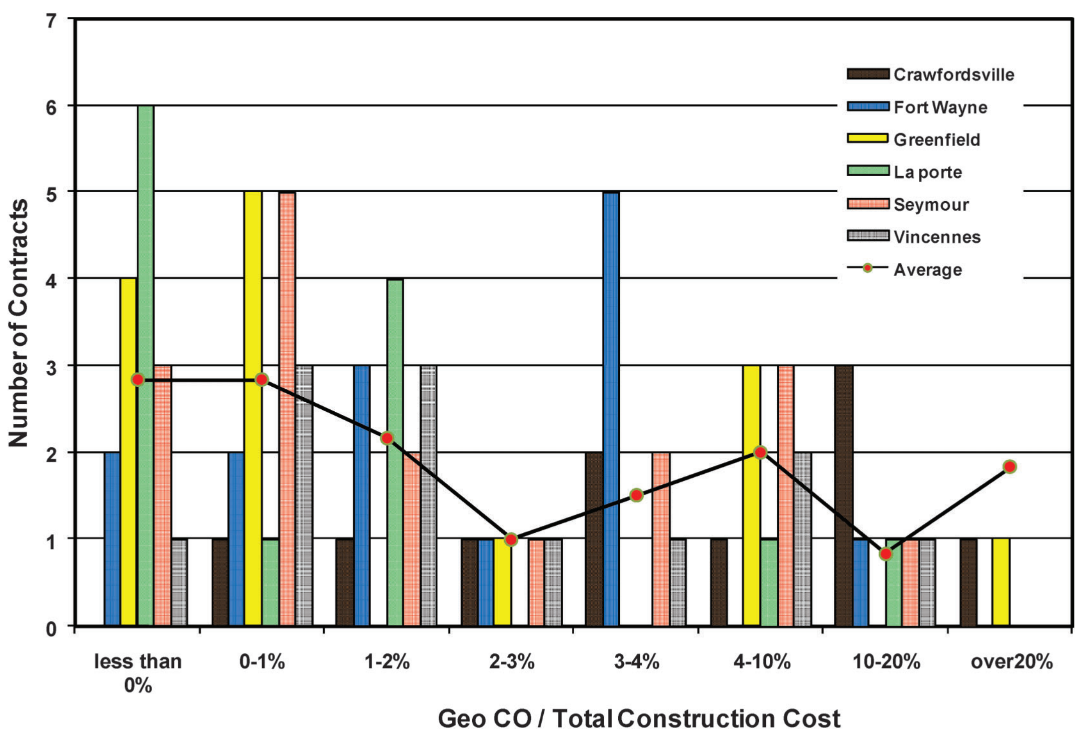


Figure 5.26 Number of contracts vs. percent geo CO out of total construction cost

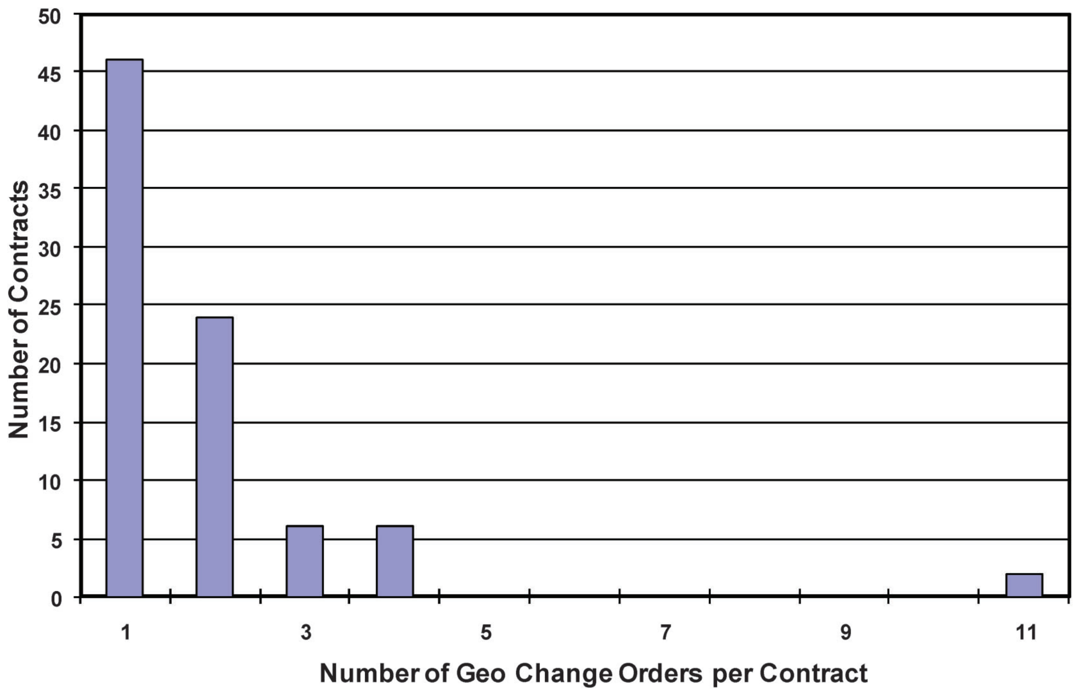


Figure 5.27 Number of Contracts vs. Number of change orders/contract

TABLE 5.15
Distribution of contracts in percent ranges of net geotechnical overruns

Percentage of Geotech. CO in terms of Construction Cost	Number of Contracts – District wise						
	Crawford-sville	Fort Wayne	Green-field	La Porte	Seymour	Vincen-nes	Average
less than 0%	0	2	4	6	3	1	3
0–1%	1	2	5	1	5	3	3
1–2%	1	3	0	4	2	3	2
2–3%	1	1	1	0	1	1	1
3–4%	2	5	0	0	2	1	2
4–10%	1	0	3	1	3	2	2
10–20%	3	1	0	1	1	1	1
over20%	1	0	1	0	0	0	2

TABLE 5.16
Number of geotechnical CO/contract vs. Number of contracts

Number of Geotechnical CO/contract	Number of contracts
1	46
2	24
3	6
4	6
5	0
6	0
7	0
8	0
9	0
10	0
11	2

TABLE 5.17
Distribution of number of geotechnical change orders

Year	Crawford-sville	FortWayne	Green-field	LaPorte	Seymour	Vincen-nes	Total	AVG
2003	0	6	5	4	6	6	27	4.50
2004	1	1	4	3	3	3	15	2.50
2005	5	8	6	9	12	13	53	8.83
2006	5	7	6	7	4	2	31	5.17
2007	4	3	4	3	4	15	33	5.50
Total	15	25	26	29	39	25	159	

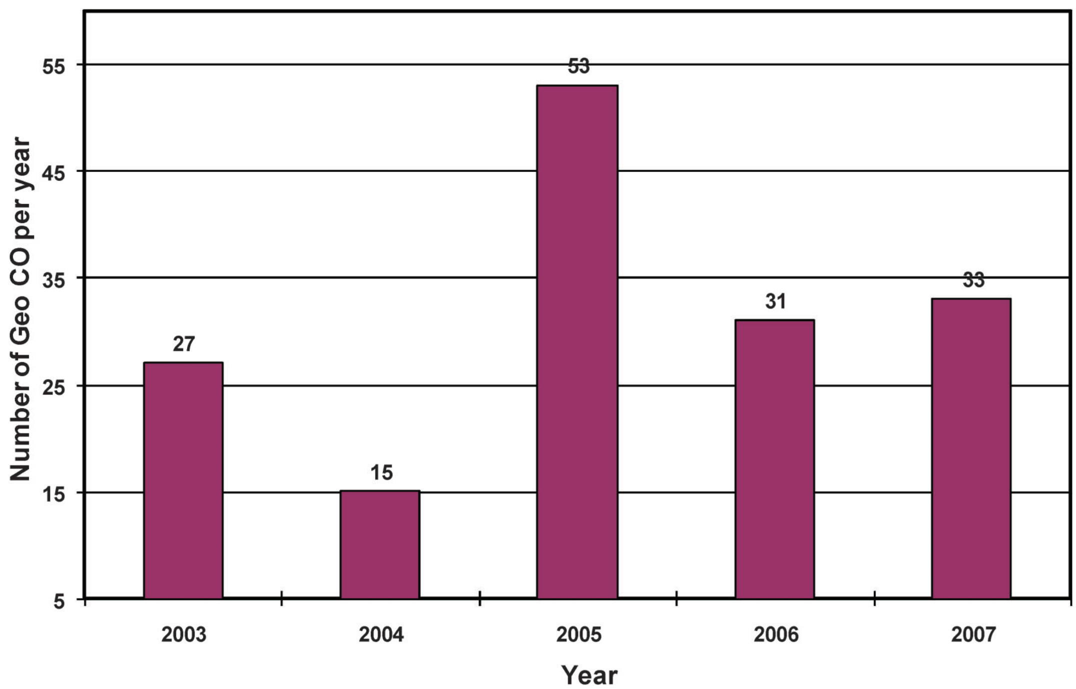


Figure 5.28 Number of geotechnical change orders vs. Year: 2003–2007

TABLE 5.18
Geotechnical change order data for road contracts

		Amounts in Thousands of Dollars – District Wise						
Category	Year	Crawford-sville	Fort Wayne	Green-field	LaPorte	Seymour	Vincen-nes	Average
Net Overrun in Geo CO	2003	0	164	43	−39	175	17	43
	2004	0	43	238	853	377	27	238
	2005	119	543	8203	484	1566	1642	8203
	2006	181	615	2318	−1	20	38	2318
	2007	1160	238	146	1401	6	602	146
Geo CO as a % of Total Construction Cost	2003	0.00%	0.77%	0.06%	−0.21%	0.27%	0.29%	0.20%
	2004	0.00%	0.29%	0.25%	3.59%	0.51%	0.14%	0.66%
	2005	0.53%	1.90%	9.07%	1.26%	3.17%	6.15%	4.90%
	2006	0.72%	1.03%	2.67%	−0.02%	0.36%	0.12%	1.49%
	2007	6.79%	3.09%	0.24%	5.42%	0.02%	0.34%	1.13%

TABLE 5.19
Geotechnical change order data for bridge contracts

Category	Year	Amounts in Thousands of Dollars – District Wise						
		Crawford-sville	Fort Wayne	Green-field	LaPorte	Seymour	Vinc-enes	Average
Net Overrun in Geo CO	2003	0	0	0	0	95	109	34
	2004	44	0	−51	−26	0	0	−5
	2005	97	0	0	0	0	0	16
	2006	88	0	0	15	98	0	34
	2007	73	0	0	0	69	0	24
Geo CO as a % of Total Construction Cost	2003	0.00%	0.00%	0.00%	0.00%	7.65%	0.39%	0.38%
	2004	1.22%	0.00%	−0.73%	−0.42%	0.00%	0.00%	−0.17%
	2005	6.28%	0.00%	0.00%	0.00%	0.00%	0.00%	1.00%
	2006	3.11%	0.00%	0.00%	0.38%	2.50%	0.00%	1.78%

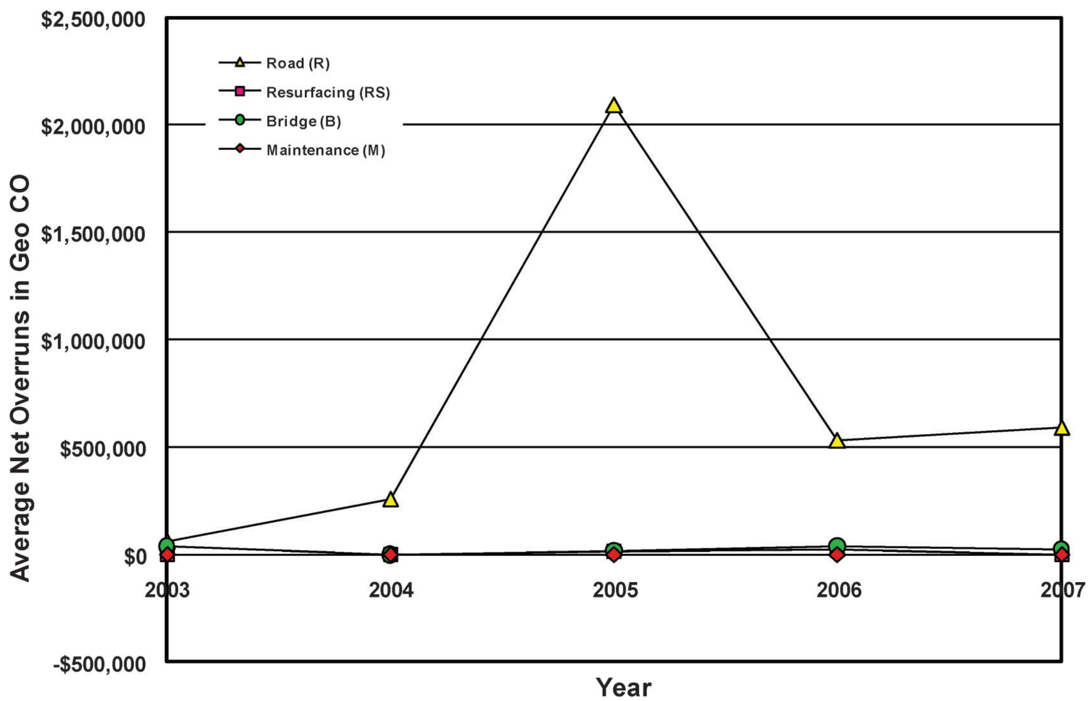


Figure 5.29 Variation of average net overruns in geotechnical change orders among contract types: 2003–2007

TABLE 5.20
Occurrence of Geotechnical reason codes

Type	Reason Code	Crawfor-dsville	Fort Wayne	Green-field	LaPorte	Seymour	Vinc ennes	Sum
Errors & Omissions - 108	108	1	1	0	1	6	2	11
Construct ability – 206	206	11	18	19	17	19	17	101
Changed Field Conditions - 405	405	3	6	6	11	14	6	46
Total	Total	15	25	25	29	39	25	158

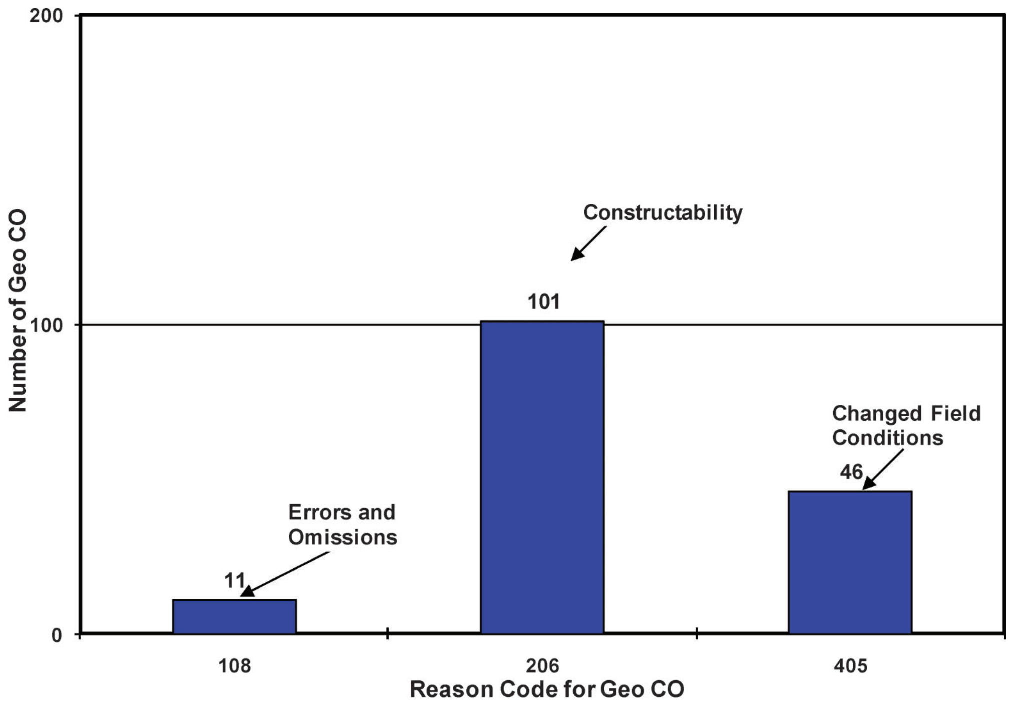


Figure 5.30 Number of geotechnical change orders vs. Reason code

district was presented by means of simple descriptive statistics such as bar graphs, scatter plots and pie charts. Data for contract costs, change orders in soil-related items, geotechnical change orders, contract types and various reason codes was presented. In order to assess the occurrence of change orders with geotechnical reasons, the data in section 5.4 was deemed to be more relevant considering that it contains only the data for change orders with soils-related reason codes 108, 206 and 405. Section 5.3 presented the change order information for all soil-related items, which may be of use from a construction quantities perspective.

The average geotechnical change order amount per district per year was 1.34 percent of the total estimated construction cost per district per year. The average geotechnical change order amount per district per year was 10.25 percent of the average amount of total change orders per district per year. The average net overrun due to geotechnical change orders was $707,000 per district per year. About 28 percent of the contracts that were considered in this study experienced geotechnical change orders. Out of the 300 contracts examined, 84 contracts experienced geotechnical change orders. In total, 158 geotechnical change orders were recorded in all the contracts. Out of the 84 contracts that experienced geotechnical change orders, there were 64 road contracts, 16 bridge contracts and 4 resurfacing projects.46 contracts (out of the 84 contracts that underwent geotechnical change orders) experienced only one geotechnical change order, while 24 contracts experienced 2 geotechnical change orders. About 41% of the total road contracts (155 contracts) experienced geotechnical change orders. About 37% of the total bridge contracts (44 contracts) experienced geotechnical change orders. The other contract types of this study's dataset were insignificant as far as geotechnical change orders were concerned. Reason code 206 – Constructability: Soils-Related – was assigned to 101 geotechnical change orders. Reason code 405 – Changed Field Conditions: Soils-Related – was assigned to 46 geotechnical change orders. Reason code 108 – Errors and Omissions: Soils-Related – was assigned to the 11 remaining geotechnical change orders. When compared to the total number of items that underwent change due to Errors and Omissions in all change orders (637), the occurrence of errors and omissions in geotechnical change orders is relatively low, which is a positive sign.

The descriptive statistics presented in this Chapter were useful in obtaining a fair picture of the geotechnical change order scene in Indiana. From the data presented in this Chapter, relatively problematic areas in terms of districts and reasons for change orders were identified in order to progress towards prevention or better management of change orders.

CHAPTER 6. INTERVIEWS

6.1. Introduction

In the previous chapter, we observed the trends in geotechnical change order data. Though the data reflects where the geotechnical change orders are concentrated, it is important to seek additional information from personnel involved with change orders on a regular basis, for two reasons:

1. The information on the contract documents was not sufficient to capture accurately the typical reasons for geotechnical change orders. This was mainly due to reason codes that portray causes for change orders at a superficial level.
2. Any amount of data may not compensate for the field experiences of personnel who have dealt with and continue to deal with change orders on a day-to-day basis.

Thus, in keeping with the objectives of the project, interviews were conducted with ten INDOT project engineers and four geotechnical design consultants who were involved with geotechnical change orders or change orders associated with soil-related items that were part of the contracts covered in the dataset. Since these contracts were completed a few years prior to the time of the interview, the change orders being even further in the past, the interviewees were mostly not able to recollect specific change orders. However, due to their continued experience with change orders, they were able to narrow down on typical causes for geotechnical change orders. Also, a few interviewees were able to discuss the general quality control methods at INDOT and their improvement. We thank these project engineers (current or former INDOT staff) and geotechnical consultants for spending their time in patiently sharing their experiences with us. In this chapter, we shall look into the vital information obtained from the interviews conducted.

6.2. Interviews with Project Engineers

6.2.1. Questions

Before looking at all the opinions and experiences shared by different interviewees, we shall first describe the basis for selection of particular projects and respective project engineers for the interviews and the typical questions put forward to them. The top four or five contracts, in terms of the geotechnical change orders as a percentage of the total construction cost, were chosen from each of the six districts. From these contracts, the INDOT project engineers who worked on the contracts were identified and their contact information was obtained from the district offices. Interviews were conducted either in person or via telephone depending on the availability of the engineers. Prior to the interview, the interviewees were presented with an overview of the project and a typical questionnaire that was sent to them via e-mail. Along with it the change order information for the particular project in contention was also provided. The essential questions, in a condensed form, that were part of the questionnaire were:

1. What were the geotechnical reasons for each of the change orders on the project? How were they managed? How could they have been foreseen / prevented?
2. How would you rate the geotechnical work done on the project with respect to site investigation, treatment of wet or soft subgrade, foundation design, appropriateness of design methods, QA/QC procedures? Would you attribute change order occurrence to deficiencies in any of the above procedures? If so, how better could the work have been performed?
3. In your experience have you observed a specific trend in geotechnical change orders? Have specific reasons come up very often? Are particular project types – Road, Bridge, Maintenance, Traffic or Resurfacing – or particular districts most affected by geotechnical change orders?
4. What would be your suggestions to INDOT in order to minimize the occurrence of change orders? Provide any other information or opinions that you may feel is relevant.

Based on their answers to these questions further relevant questions of greater depth, were asked depending on the progression of the conversation. As mentioned earlier, due to the fact that most of these change orders had occurred a few years previously, the project engineers found it very difficult to recollect and reproduce exact situations and reasons behind them. Hence, their answers tended to be more general and based on their observations and experiences from all the projects they had worked in and not particular to the change orders from a particular contract.

6.2.2. Answers

Now, we shall look at all the answers, opinions, statements and suggestions from the project engineers who were interviewed. Considering that our objective is to only improve on change order management for the future, and in order to keep the identities of interviewees secure, we will refer to them as Project Engineers A, B and so on. The change orders described could be due to geotechnical reasons or may be due to other reasons and involve soil-related items recorded as part of the change order.

Project Engineer A

Project Engineer A's answers only addressed the one particular contract, where he was the project engineer, for which the change order information was provided to him. This was a road contract where there were a couple of change orders that were pertaining to geotechnical work. Project Engineer A recollected that the major change order in terms of cost overruns from this project was from the treatment of poor subgrade soil. The necessity for soil treatment was identified in the plans. It was also planned that the existing pavement would be recycled in order to provide the fill material once the undercutting was performed on the poor subgrade soil. However, the recycled material from the existing pavement was found to be short and would not be sufficient to fill the undercut volume beneath. Hence a large amount of money was involved in purchasing new #53 stone in order to be able to fill this remaining undercut zone. The shortage of fill material was close to 70,000 tonnes, and the major cost overrun was due to the need to purchase new stone to fill the undercut portion.

According to Project Engineer A, this error in design was unique to this project and is not very common. It could have been prevented if the designers had made a reasonable estimate of the amount of recycled fill they would obtain from the existing pavement and whether it would be sufficient for filling the undercut volume. The designers would have to adopt better methods to predict more exact amounts of recycled material that would be available for use in the new project.

Another source of change orders in this project was from erosion control. The quantities proposed by designers were insufficient. Extra amounts of rip-rap and geotextiles were required in order to protect the existing pipelines; this was not accounted for in the initial plan, as mentioned Project Engineer A.

Project Engineer B

Project Engineer B spoke about the change orders with respect to geotechnical work on a road contract which he was involved in, which had significant geotechnical change order amounts. The main source of change orders on this project was due to the extra excavation that needed to be carried out along the length of the project. The contractors were provided the bench mark elevation with the datum of measurement being 6 inches off where it should have been. Hence, a length of 37,000 yards needed to be excavated with this depth; this resulted in a large cost overrun in the project. That was considered a very rare error that cost the extra money needed to pay off the excavation costs. This is again very unique to this project and not what one would expect very often.

In addition to the change order mentioned above, bridge rails were constructed along the length of a bridge in the project. The designs indicated that the rain water would collect along these bridge rails. But as water across the bridge flowed into the rails, it ran-off towards the end of the bridge and, at this location, the designs did not make any arrangement to collect this water that runs off to the end of the bridge rails. Thus, rip-raps and geotextiles needed to be placed in order to handle this drainage of water towards the end of the bridge, with flat drainage lines near the edge. This change order could have been easily prevented by a design that considered a very certain necessity of the project, Project Engineer B remarked.

Project Engineer B explained that there were also change orders related to piling on this project. The piling quantities from the Pile Driving Analyzer (PDA) testing on the test pile did not match the actual requirements. During pile driving it was found that the results were underestimated on the test pile driving. The design pile quantities did not match the actual pile driving quantities that were used in the field. Hence, there were cost overruns to manage this problem. Project Engineer B also recollected that during this project questions were raised regarding the effectiveness or accuracy of the PDA testing.

Project Engineer C

Project Engineer C discussed the geotechnical work and the change orders from his project, which was shortlisted based on change order amounts. Here, it was seen that though the change orders involved geotechnical work including excavation, aggregate and geotextiles, all the changes were due to a scope change from a Local Agency Request, as described by the reason code. The changes were mostly due to political reasons and had no geotechnical background.

Hence, Project Engineer C resorted to answering the questions from a more general point of view based on his experiences with geotechnical change orders in various other projects. He cited erosion control as one of the major reasons that demanded that change orders be recorded, very frequently. Also, he mentioned that insufficient site investigation tended to be a very important reason for geotechnical change orders, in the projects he had worked on. Especially in contracts that are 'shelved' for a long time, he felt that the site investigation was typically done far too ahead of the construction period which resulted in lot of changed field conditions. For rectifying this problem, he suggested that for projects that are shelved, a secondary site investigation needed to be done to make sure there are no changes from the initial conditions. Also, Project Engineer C felt that designers lacked knowledge of field conditions a lot of times and tended to work with maps and old plans, which were not reflective of actual field conditions. This, according to him, was a reason for geotechnical change orders. Mismatch in piling quantities was also an issue to be addressed, he expressed. He also said that road projects that spanned over several miles tended to produce the most number of change orders.

With regards to the soil treatment methods usually used, Project Engineer C felt that it was more important to adhere to experience rather than to specifications when it came to treatment of poor subgrade soil. The method of treatment for a particular condition would be better determined at the site, rather than by using specifications, which may not cover or account for the various conditions that prevail on the project.

Project Engineer D

Project Engineer D reviewed the change orders for a road project where the change order amounts for geotechnical work were relatively high. He was on the project only for half the duration of the contract and, hence, addressed only the change orders that occurred during that time.

Project Engineer D recollected that for soil treatment, a special provision was included in the contract to allow the crushing of recycled concrete pavement into stone for filling undercuts. The contractor was initially going to use this option but eventually decided against it as he felt that it would not be cost effective considering that there was abundant availability of #53 stone in the area that could be used for filling the undercut locations. Also, there was another change order involving aggregate amounts which was due to a change in scope on the project and, the reasons were not geotechnical, quoted Project Engineer D. The project was designed so that a portion of an intersection with a city street would be built along with the street. However, during construction it made more sense to construct it right away and so it was decided to extend the embankment and build the entire intersection with the project. This resulted in extra aggregate, embankment and subbase. Also, as far as other change orders with geotechnical items, he recollected that a special provision required guardrail in certain ditches. The road plans did not include quantities of riprap for these and, hence, a change order was recorded for this. Overall, Project Engineer D felt that geotechnical issues were not crucial in this project and that the change orders associated with them were well handled. In general, he indicated that geotechnical change orders are not very problematic in his experience. In order to avoid some of them, extensive site investigation might be a solution but he was not sure what the "cost-benefit ratio" would amount to and was of the opinion that mostly it might be cheaper to pay for overlooked items rather than spend more on more intensive testing.

Project Engineer E

Project engineer E dealt with a road project that included very high amounts associated with geotechnical change orders. This contract was handled by local agencies and was not under the direct supervision of the State. He mentioned that geotechnical change orders were the most difficult to handle on the project. Great time and effort was spent to ensure that the change orders were detailed sufficiently so all parties knew the conditions and responsibilities included in the work.

There were four geotechnical change orders on the project. The first geotechnical change order was for the deletion of the planned Dynamic Compaction item and it reimbursed the contractor for eligible charges incurred. The second geotechnical change order was for the removal/replacement method of subgrade improvement adopted on this project. The third geotechnical change order was for a geogrid change and addition of an item for #2 stone to be used in the undercut area. The fourth geotechnical change order was concerning settling a claim for some of the geotechnical work performed on the project in cold weather and for payment for #53 gravel and stone used by the contractor.

Project Engineer E described in detail each of the change orders and the background behind their occurrences. While describing the change orders, Project Engineer E also covered the techniques and processes adopted in the work. Though they might be irrelevant to the reasons causing the change orders, the approaches towards site investigation and quality control, as described by Project Engineer E are quoted here, and this is a good chance to capture some of the methods adopted in INDOT contracts. Along with this, we shall describe his explanations of the change orders one by one.

The site investigation for the project was carried out by a geotechnical firm that recommended dynamic compaction in order to reduce the voids in the soil caused due to the broken concrete slabs that had been dumped for several years, and thus reduce settlement. Accordingly, the firm wrote the Special Provisions for dynamic compaction and this was included in the Special Provisions for the contract. These Special Provisions gave very specific directions as to how dynamic compaction was to be carried out and the measures to be taken for ensuring good results with dynamic compaction. The subcontractor in charge of dynamic compaction had to submit a work plan that had to be checked for agreement with the Special Provisions prepared.

The pre-dynamic compaction soil borings and SPT samples were obtained by another geotechnical consulting firm. Water levels at the borings were measured and the buildings in the surrounding area were recorded on video to document existing conditions. A seismograph was used to record vibrations during dynamic compaction. Dynamic compaction was performed in the area – 40' drop height, five to seven drops on an eight-inch grid. After dynamic compaction was completed in the test area, soil borings were made and SPT samples were obtained again. Water levels were measured again. The results pre-compaction and post-compaction were compared. The results post compaction did not meet the standard criterion – average SPT N- value of 20 blows per foot with N-values not less than 15 blows per foot. Hence, a second test area was chosen and the method of dynamic compaction was revised to a 50' drop, eight drops on an eight-inch grid. Pre-dynamic compaction soil borings were done in this new test area, followed by dynamic compaction, followed by post dynamic compaction soil borings. The criterion was not met again.

The relevant authorities and personnel on the project met in order to review the work and assess the situation. The decision was made to use the more conventional method of removal and replacement. Hence, the first geotechnical change order deleted the item for dynamic compaction, but recorded reimbursement of allowable charges incurred by the contractor.

The geotechnical firm that prescribed dynamic compaction declined to carry out the undercutting and replacement of the poor quality fill. Hence, a different firm was hired to carry out this work. This firm identified that two of the four borings taken by the initially appointed company did not extend in to the native material and hence additional soil borings and tests were performed. The recommendations included 1.22 m removal of soil in the cut and fill sections. The 1.22 m undercut was from the plan subgrade elevation in the cut sections and from the existing ground elevation in the fill sections. #53 gravel was used in the fill section, undercut to within 1.216 m of the subgrade. The top 1.216 m was 0.608 m of #53 Stone on 0.608 m of #53 gravel for both cut and fill sections. Geogrids and geotextile were placed on the bottom of the undercut for cut and fill sections and at the existing ground elevation on the fill section. Pneumatic Settlement Cells and a Pneumatic Standpipe Piezometer were added at the request of INDOT Geotechnical office to monitor settlement in the fill section. Settlement plates were also used to monitor the settlement. The second geotechnical change order included costs for the additional construction required by this revised method of construction.

The removal and replacement Geotechnical Report specified Tensar BX1200 or equivalent geogrid usage. The author of the report later approved any Type 1 Geogrid from INDOT's list of approved materials. INDOT Geotechnical division denied the change in the first place and asked for the original geogrid type to be used. Thus, the third change order created a specific item of geogrid for Tensar BX1200. Also, there was an extremely wet area where #2 stone was used to stabilize the grade and an item for #2 stone was also added onto this change order.

The project was constructed as planned with the exception of Hot Mix Asphalt (HMA) surfacing work, during a particular year. Accordingly, HMA surfacing and some other miscellaneous work would be completed in the Spring of the following year. This was recommended in the consultants' subgrade recommendation report. The unit price for HMA Surface and HMA for Sidewalk and a few other items was increased to reflect the price increase for work originally planned to be completed in the previous year, but would now be done during the following Spring. INDOT agreed to pay the contractor for cold weather work, up-charge for HMA intermediate that was not placed in the previous year and also agreed to pay plan quantities for the #53 gravel and #53 stone items on this project. All these items were included in the fourth change order. This is an example of a change order in geotechnical work, which was not due to geotechnical reasons.

Despite the heavy increase in costs due to the change order concerning subgrade treatment using dynamic compaction, Project Engineer E was of the opinion that sometimes such change orders are inevitable. In the report prepared by the firm that suggested dynamic compaction, the following was mentioned, according to Project Engineer E - "The most reliable construction method for this roadway would be to remove and replace the existing fill……this option of construction would be costly. Therefore, it is recommended that the site be improved by dynamic compaction…" Hence, he feels that they went with a less conservative approach than the one they had in hand but it did not work out in this case. The geotechnical firm felt that the acceptance criteria were unachievable and claimed that, "Improvement of such soils using Dynamic compaction will be limited. The criteria in the Special Provisions should be waived and the dynamic compaction be accepted on the basis of a three-inch difference in crater depth on successive drops of the weight," stated Project Engineer E. This recommendation was denied and the removal and replacement method was followed. As far as the QA/QC procedures for this change order is concerned, Project Engineer E recollected that they had inspectors in place all the time to ensure specifications of the Special Provisions were met since INDOT rarely carries out dynamic compaction.

In general, Project Engineer E felt that there is always some amount of uncertainty associated with underground work and hence the most common approach would be to proceed with the plans as long as possible and then deal with the changes when they are encountered. However, he felt that when changes occur, decisions need to be made as fast as possible and the changes managed quickly. He mentioned that due to the quick handling of changes on this project, the cost increase was considerably cut down. Also, he stated that he would expect most changes to occur on long road projects, due to subgrade issues, and in bridge piling.

Project Engineer F

Project Engineer F was contacted based on the relatively high amount of geotechnical change order amounts on a road contract he worked on. He confessed that the contract was too far in the past for him to recollect exact details from it. However he tried to narrate some of the issues on the project and also spoke about some of the other contracts where he encountered geotechnical changes. We will look at his answers and opinions, reported from a first person view:

According to Project Engineer F, "Geotechnical issues were not the dominant reason for change orders (on this contract). There was a need for change orders to address undercutting of poor soil and the placement of 53 compacted aggregate at various locations. These locations were determined by proof rolling (loaded tri-axle truck). INDOT's specifications address this situation on how the related payment will be handled and how to check for proper subgrade strength. However, there are times when this situation can become difficult to solve if the area of poor soil is deep and large. Then, undercutting and replacement with #53 stone may not be the most cost effective method of correction. INDOT's Geotechnical Section in Indianapolis is then consulted to seek additional advice to find a more cost-effective solution."

Project Engineer F also mentioned that "Basically, we had many areas of the subgrade that failed proof rolling due to poor soils - gray soft soil, and deteriorating vegetation, such as wood. Most of these areas were corrected using 1 foot or less of undercut and replacement with #53 stone. The costs associated with the correction work were those for additional excavation and placement of #53 Stone."

On addressing the problem of geotechnical change orders, Project Engineer F stated that "My experience has been that often, not enough soil borings are taken or that the soil borings are not taken in the appropriate locations. I believe INDOT should have more oversight on the locations of the soil borings. Also, there are times when a particular type of subgrade treatment would be more appropriate for certain types of existing soils. As an example, Project Engineer F recalled another contract that was constructed a couple of years ago which called for Type IV treatment - 9 inches of subgrade excavated and replaced with coarse aggregate #53 on geogrid. This was a bad choice because the majority of the soil on this jobsite was red clay that was soft (wet). Therefore, the planned subgrade treatment was not sufficient to correct the soft clay soil problem. Project Engineer F mentioned, he believed that the best method would have been Type I (with only the 16 inch chemical soil modification). Instead, the contractors ended up undercutting large volumes of soil and backfilling with #53 stone and shot rock (large rock of various sizes that is the result of blasting in the rock quarry).

On being asked about the appropriateness of specifications and guidelines, Project Engineer F said, "INDOT specifications, guidelines and testing requirements are sufficient. I would like to see the DCP (Dynamic Cone Penetration) be allowed on all soil testing. More timely results are achieved in the field with this method."

When asked about the change orders he had encountered which he felt could have been foreseen and, hence, been avoided, he said, "On a large road contract such as this, INDOT expects change orders for geotechnical issues because the existing site conditions are going to vary throughout the jobsite, and these variations are very difficult to find prior to excavating the area. However, the poor soil has to be removed. Considering INDOT expects poor soil to be encountered on a contract of this size, an estimated quantity could have been included in the original bid for the contract to reduce the amount of change order cost associated with geotechnical issues. The reason for frequently encountering poor subgrade soil, in some cases, may be due to the fact that not enough soil borings are taken to correctly identify all the issues on a jobsite." Project Engineer F also indicated that he is currently working on a contract that will require a change order for a large overrun in rock excavation because soil borings were not taken in a large cut section of the jobsite (all the cut was expected to be soil, but instead a large part is rock). Project Engineer F mentioned that soil borings taken at this cut section should have identified this issue prior to letting and thus, eliminated the need for a change order.

On the dependence of geotechnical change orders on contract type and location, Project Engineer F remarked, "The locations of contracts do present different geotechnical issues. Some areas have a greater chance for rock, some peat, some soft clay, some springs, some silt. Mostly, contracts involving complete new pavement sections will involve geotechnical change orders. Usually, only the bridge work ends up being as planned."

As suggestions for preventing geotechnical change orders, Project Engineer F mentioned the following:

1. "Undistributed quantities could be included in the contract at the time of bid to cover some of the estimated geotechnical issues that are highly likely to occur.
2. Unit prices should be established against other bidders as they are normally more favorable to INDOT than establishing a unit price after the letting, with no other bidders being involved.
3. For the subgrade issues, better performance is required when it comes to soil borings. Some planned quantity for removal and replacement of poor soil encountered should be included because this problem should be expected based upon the history of the work. More care is required with the choice of the subgrade treatment type based upon the region of the state and the associated soil types expected."
4. The location of a contract needs to raise some "red flags" while conducting geotechnical investigations. Different approaches need to be adopted at different regions of the state.
5. A check list could be developed, including all the possible problems, and used during the design process. The check list could be developed based upon change order issues that repeatedly occur and be based upon the region of the work as certain issues arise in one region, but do not in another."

Project Engineer G

Project Engineer G spoke about the change orders in a road contract that was part of the dataset considered in this study. His answers were mostly specific to this one contract, though he provided a few suggestions based on other experiences. He mentioned that the geotechnical change orders were relatively easy to process and explain for this contract. Most were errors and omissions in the original quantities or in the items added, such as riprap and geotextiles used with riprap, all to stabilize areas subject to erosion. We will briefly look into his descriptions of each change order on the project.

One change order was concerned with temporary erosion and sediment control. The relevant items for this work were shown in the erosion control plan, but were not included in the proposal of pay items. Thus, this change order dealt with including these items. In another change order, an item for B-Borrow for structure backfill was decreased and another item of aggregate was added. The contractor preferred to fill three box structures with #12 aggregate over using #23 sand. The specifications currently allow for aggregate to be used as backfill. The B-Borrow for the structure backfill would have had to be placed in six-inch lifts and compacted, while the #12 aggregate could be placed in 12-inch lifts. This was purely a constructability-based issue.

Project Engineer G mentioned that in another change order, revetment riprap and geotextiles, to go with the riprap, were added for usage at several locations where the necessity was felt. Bituminous curbs were removed to direct the flow of water at a river bank and at steep areas of the bank, there was a need for erosion control. Use of revetment riprap was adopted as the logical solution and extra revetment riprap was included through change orders, especially behind one guardrail and the rest for areas that required erosion control.

Project Engineer G indicated that a change order dealt with the extra #53 aggregate required due to a possible error in calculation of quantities. This change order also included further addition of riprap for usage along the banks of a river. One more change order was associated with wrong calculations on aggregate quantities, due to not accounting for an area of excavation and backfilling.

A change order was recorded for the placement of an erosion control blanket for a slope that required a good stand of vegetation. A good stand of grass with minimal erosion problems was achieved as a result. Also, a final change order was associated with an underrun in subgrade treatment quantities from the plan, possibly from an error in calculation.

These were the descriptions of each of the change orders involving geotechnical items, as provided by Project Engineer G. He also provided some general views on geotechnical change orders. He felt that a lot of change orders occurred with respect to subgrade treatment on rehabilitation and new jobs. One point which he strongly emphasized on was that the reason codes were not always most appropriate for use and that it is often very difficult to determine which reason code to use for each change order. Project Engineer G stated that change orders are inevitably going to be written on most contracts and that he felt that geotechnical issues were fairly well-covered as far as preventing change orders is concerned. He mentioned that riprap and aggregate quantities never matched the ones on the plan. Project Engineer G stressed on the fact that it would be much wiser to rectify a bad situation while a contract is active rather than let INDOT Maintenance come back to work on it because then it would be 100 percent State funded. When asked about frequent reasons for change orders and dependence on project types and location, Project Engineer G commented that mismatch in quantities, especially those related to riprap and aggregate, was a frequent issue. He said that he had worked only in Greenfield, and considering that this district strives to deliver high quality jobs, change orders are going to be part and parcel of these contracts. In his opinion, large road projects and rehabilitation projects are most prone to change orders.

Project Engineer G also mentioned that increase in the minimum amount that warrants the recording of a change order would decrease the number of change orders. However, the fact that change orders now need to be operation specific means that he expects a greater number of change orders.

Project Engineer H

Project Engineer H discussed the change orders from a road project he worked on that was part of the dataset considered in this study. He spoke about some of the issues he could recollect from the project and also provided his views on geotechnical change orders in general.

According to Project Engineer H, the majority of the geotechnical overruns where due to the addition of 2 miles of passing lanes added under one change order. All of the area was in a fill-cut section, with the existing fill and a new fill added to get the desired lane width. Project Engineer H mentioned that this change order was due to political reasons. This change came up during the course of the project and it could not have been foreseen or prevented. According to him, this was one more change order involving geotechnical items that did not occur due to geotechnical reasons.

Project Engineer H indicated that the second area of increase was due to the necessity of realignment of the pavement due to political reasons again. There was a large cut area at the sub grade which was very soft material and it was determined that it would be cheaper to remove 18 inches of soil and treat chemically rather than undercutting and replacing with B-Borrow soil.

In another change order mentioned by Project Engineer H, turn lanes and passing lanes were to be added. A temporary pavement was to be constructed to allow traffic flow. However, for some reason the plans indicated that the soil under the temporary lane had to be treated but there was no soil treatment prescribed for the permanent pavement that was being constructed. According to him, it made no sense to treat the soil for the temporary lane and not treat it for the permanent lane considering that they were really close to each other and that the soil was pretty much the same. The temporary lane was going to be stripped off anyway in three months' time. Thus, a new order was made to treat the soil under the main permanent pavement as well. Due to cheaper costs of treating the soil up to 18 inch depth rather than under-cutting the entire layer and replacing with B-Borrow, soil treatment methods were adopted. Lime-flyash stabilization was used to treat the soil. This has been a very productive method that has been observed to yield very good results in his experience, stated Project Engineer H. For the quality control of soil treatment, fly ash was obtained after it was tested in the laboratory. He opined that the need for this change order was probably due to the lack of sufficient site investigation and faulty design plans. He said he didn't know who performed the site investigation, but suggested site investigation should have certainly been short. According to him, in most such cases, the designers cannot be blamed because they just follow the pavement design plans they are provided with.

In Project Engineer H's experience, there have been issues with site investigation. There were projects which he worked on where the undercutting had to be increased more than 200% due to insufficient site investigation. According to him, there was the need for sudden soil treatment or unexpected ditches, pipes, tanks, garbage dumps that were encountered and had to be dealt with during the construction of the projects.

Project Engineer H explained that generally change orders could be prevented by cultivating the right attitude. Change orders basically crop up due to attempts made at the planning stage to cut down on costs excessively and, eventually, when the construction begins, it is found that things which were planned and had to be compromised on for the sake of cost-cutting need to be eventually done anyway and, hence, there are change orders. "A sound plan that does not risk any unnecessary compromises should help in cutting down change orders," said Project Engineer H.

Project Engineer I

Project Engineer I provided a very brief summary of the problems encountered in his contract, which was included in the data for this study. Due to constraints of time and availability more information could not be obtained from Project Engineer I.

He mentioned that on this road contract, some of the change orders recorded, including geotechnical items, were from quantity issues due to replacement of Grated-Box End Sections to Pipe-End Sections because the Grated-Box End Sections, which are more expensive, were not required to meet the clear zone and safety requirements. He indicated that this did not exactly qualify under geotechnical reasons but was recorded with geotechnical items. Also, there were issues on the project with respect to flattening the foreslopes as planned due to:

1. At places, the right of way was insufficient to move the back slope.
2. Where right of way was sufficient, the subsoil was so granular that once the turf was removed, preventing the slope from sliding before it could be encased was a challenge.

   Project Engineer I also mentioned that he encountered many problems with elevations given on the plans in this contract. This led to a lot of cases where the plans indicated filling of ditches which had pipes, and this immediately resulted in flooding of adjacent property. Quite a few changes occurred due to similar problems with elevations, recollected Project Engineer I.

Project Engineer J

Due to his inability to recollect issues from the contract and explain situations better than the contract documents, Project Engineer J preferred to discuss the problem of geotechnical change orders in a general way, based on his varied experiences on several contracts. We shall now describe briefly his experiences with frequently occurring geotechnical problems on INDOT construction contracts and the procedures, specifications and QA/QC methods associated with these problems.

The most common problem that caused geotechnical change orders, in his experience, was the subgrade treatment problem. He observed that there are rarely any issues with the foundation design as these are carried out exactly as how the designs specify them to be and there is not much scope for change. Typical change order problems would be for dealing with poor subgrade. In the case of poor subgrade conditions the specifications provide two options, said Project Engineer J:

1. Undercutting about 1 foot of the soft layer and replacing it with generally #2 stone or #8 coarse aggregate (some cases #53).
2. Lime stabilization for about 16 inches to strengthen poor soils.

According to Project Engineer J, the first option was the more popular one until about five years ago. However, he felt that this is not the most effective way to deal with the problem. He said, "Just replacing about one foot of the soil with stone or coarse aggregate on top of the remaining poor soil really does not tackle the problem effectively. Nowadays, lime stabilization is more popular and is a more effective way of overcoming poor subgrade problems."

He continued saying, "Now, once the subgrade has been treated by either method, the specifications require that the soil is compacted to a specified density and that a DCPT criterion is satisfied. A certain count for the DCP should be reached for the first six inches of penetration and for the subsequent six inches. This is a standard count and it would be much better if the count was specified more accurately for every soil type that existed on the field, as the count tends to vary quite a bit for different types of soils. Traditionally, once the specifications are met, "proof-rolling" is done. This is a process where a fully-loaded tri-axle truck is driven across the soil to check if it withstands the truck load. Project Engineer J mentioned that it is very often seen that even though the specifications were met, the subgrade fails under the truck load. This necessitates further subgrade treatment, and results in change orders and, eventually, a cost increase. Project Engineer J indicated that the specifications should probably be sounder in this regard to prevent such change orders.

Project Engineer J also remarked, "INDOT generally prefers to deal with this issue and pay for it through change orders, rather than give any freedom to the contractors for subgrade treatment. This is because giving too much of freedom in this regard to the contractor would result in the latter treating much more soil than required and, hence, billing INDOT at a greater cost. Instead, INDOT prefers to let the contractor go on the field, meet the problem of poor soil in that location, make a change order and then treat the poor soils at those specific locations."

With regards to the solution for such problems Project Engineer J said, "A lot of these subgrade problems could be prevented if the site investigation was expanded further. Whether the cost input into more intense site investigation would be repaid by preventing late detection of poor subgrade soil is questionable. This is because the nature of occurrence of poor soil is very random, and more robust site investigation may yet fail to eliminate this problem."

Project Engineer J also felt that some geotechnical change orders occur due to the lack of ability on the part of the designer to think "three-dimensionally". They fail to recognize the actual field conditions, either due to the insufficient details provided to them or plain lack of identification with the situations of that particular site.

Another common issue that Project Engineer J has come across a few times is pertaining to MSE (Mechanically Stabilized Earth) wall construction. Project Engineer J gave the example of projects where a highway is reconstructed to widen existing pavement lanes, with the MSE walls built on the edges of the new highway. He mentioned that in most cases, the MSE wall configuration coincides with the drainage lanes, as they were located just past the boundary of the original highway. According to Project Engineer J, the specifications provide no information as to how to deal with such a problem, and this issue is never included in the plans. Thus, in the field, a lot of change orders result when drainage lines need to be eventually handled, observed Project Engineer J. Project Engineer J also called attention to the fact that the presence of ditches by the side of the original highway is an indication that there will be the need for treatment of the marshy soil that generally tends to be found there and that not many prior allowances are made for the stabilization or undercutting and replacement of the poor soils at these locations.

Project Engineer J indicated that another common reason for geotechnical change orders is in the case of pile driving for bridges. Project Engineer J feels that the development of the PDA testing is certainly an improvement because previously piles used to get over driven, with additional stresses being applied to the piles. He mentioned that quantities that are prescribed at the planning stage for pile driving are always off the actual values that are needed in the field. According to him, in the field, all the pile driving is done based on the results of the test pile driven into the ground and the PDA testing, while the prescribed values from design are obtained through soil borings done on the site during the planning stage; these two results hardly ever match, leading to change orders most of the time. Specifications must look to address this issue in the case of bridge projects, he observed.

According to Project Engineer J, additional sources of geotechnical change orders were erosion control measures that are added during the course of a contract and designs and cost estimates that never account for the existing pipes that run across the field and that invariable need to be protected using geotextiles and riprap (these are used to protect the pipes and manage the drainage pits often composed of very poor, marshy soil).

The important information from all the interviewees is summarized below in brief in Table 6.1.

In this section, we looked into all the information provided by each of the project engineers who were interviewed. In the next section, we will describe the view on geotechnical change orders of geotechnical consultants who have worked on INDOT construction contracts.

6.3. Interviews with Geotechnical Consultants

In order to obtain a different perspective of the problem of geotechnical change orders at INDOT, geotechnical design consultants, who work on INDOT projects, were also interviewed. Since these consultants perform crucial tasks, such as site investigation and soil testing, and provide the collected information to designers, their input was considered important in order to converge on practical solutions. They provided their views, comments and suggestions on the problem of geotechnical change orders. Again, in keeping with the format followed until now, we will refer to each person as Consultant A, B and so on.

6.3.1. Answers from Geotechnical Consultants

Consultant A

Consultant A representing a geotechnical firm that performs consultancy for INDOT projects, provided briefly, his opinion on geotechnical change orders.

Initially Consultant A spoke about site investigation performed by consultants in INDOT projects. He said that they performed site investigation sometimes while INDOT did it on other occasions and that this generally varies with INDOT's policy for each particular contract. He mentioned that apart from the standard borings and soil testing, his firm also visits the site several times and couples the data collected with the knowledge from aerial maps and topographic surveys in order to identify problem soils in the field. He also discussed the possibility of compromises being made sometimes in site investigation for cost-cutting, which could eventually lead to change orders during construction. The typical deficiencies in site investigation, according to him, can be insufficient boreholes, lack of sufficient knowledge about site conditions on the part of the investigator and failure to optimize the effort input and channel it to the correct areas in the field – this would happen as a result of good background studies that would help prediction of problematic areas where boreholes could be concentrated.

Consultant A also discussed some other issues that may cause geotechnical change orders, in his opinion. He felt that design consultants tended to overlook some recommendations made by geotechnical consultants as in many occasions there were issues on the field that created change orders, and when the reasons were tracked back, the conclusions were that suitable recommendations had already been made by the geotechnical consultants but that the design consultants for some reason failed to take them into account. Also, consultant A was of the opinion that the contractors needed to be dealt with a more stubborn approach and not be treated softly always. He suggested that sometimes there is "a false sense of security" between the geotechnical and design consultants, with the former trusting the latter to take into account certain issues and handle them and vice versa. Consultant A said that in many situations neither party covers all areas completely, leaving loop holes for change orders to enter. Thus, this lack of communication between geotechnical and design consultants, according to him, causes change orders in many cases.

TABLE 6.1
Salient information from Interviews with INDOT Project Engineers

Personnel Involved	Reason for Change Order	Remarks
Project Engineer A	In subgrade treatment, quantities of recycled pavement that would be generated for use in filling undercut portions, were overestimated.	Shortage of close to 70,000 tonnes of fill material. Overruns due to purchase of #53 stone.
	Erosion control and protection of existing pipelines was required.	Riprap and geotextiles were purchased.
Project Engineer B	Faulty benchmark elevation was used for calculating the quantities along length of road.	Overrun due to extra excavation of 6 inches needed along 37,000 yards.
	Drainage set up was not included in design to collect water running off from bridge rails	Riprap and geotextiles were used. Issue should have been predicted in design.
	Piling quantities obtained from design did not match the ones on the field.	Accuracy of PDA testing and design quantities needs to be improved.
Project Engineer C	——	General Remarks: Mismatch in piling quantities need to be reduced 'Shelved' projects should have a secondary site investigation
Project Engineer D	Recycled pavement usage for filling undercut portions was prescribed in design despite abundant availability of aggregate at the site. This would have proven uneconomical	Recycled pavement could be used when there is no aggregate availability on the site.
	Extra soil-related items due to scope change in construction of an intersection	——
	Riprap not included for special provision made for guardrails in places with ditches	——
Project Engineer E	For subgrade treatment, dynamic compaction was initially prescribed. After failure, undercutting and filling was adopted. Two change orders were recorded for this.	A less conservative approach was adopted to cut costs but did not work in this case.
	Geogrid type was changed. For an area of poor subgrade, undercutting and filling was done.	——
	Hot-Mix Asphalt work was delayed and contractor was compensated for some extra items and cold-weather work.	——
Project Engineer F	Change orders recorded for sub-grade treatment using undercutting and filling. More changes occurred due to treatment not satisfying specification requirements.	Soil-treatment method should be chosen with accounting better for site conditions. Engineer also opined that DCP criterion should be used comprehensively for QC, with accurate blow count criteria for specific soils.
Project Engineer G	Erosion control was included in the plan but was omitted in the proposal of pay items.	Error should have been avoided
	In placing backfill material, there was a constructability issue. Placing aggregate was easier than placing B-Borrow. Hence B-Borrow was decreased and aggregate included.	A constructability issue which could have been avoided with better foresight.
	Revetment riprap was included for erosion control where curbs were removed to allow flow of water. Steep areas needed erosion control.	An issue that could have been avoided with better knowledge of site conditions.
	Two more change orders recorded due to wrong estimation of aggregate quantities for filling and also for riprap use along the banks of the river	Miscalculation error should have been avoided.
Project Engineer H	Subgrade treatment was prescribed in the plans for a temporary lane needed for traffic regulation. But the permanent lane in the same area, with same soil had no subgrade treatment mentioned in plans. A change order was recorded to treat subgrade for permanent lane.	An issue that should have been considered in the plans. Records

TABLE 6.1
(Continued)

Personnel Involved	Reason for Change Order	Remarks
Project Engineer I	Constructability issue in flattening of foreslopes required several change orders. Either right of way was insufficient for this or the soil was too granular and preventing sliding of the slope was a challenge. Change orders recorded for this.	Better knowledge of site conditions could have prevented related change orders.
	Errors in elevations on plans resulted in a few change orders	Errors in elevations on plans should be avoided as this can result in heavy cost overruns.
Project Engineer J	——	General Remarks: Subgrade issues could be minimized through more extensive and flexible site investigation programs. Piling quantities need to match more often with improved accuracy from test pile driving. With highway extension, specifications need to account for conditions where MSE Wall configurations coincide with pipelines and areas of poor soil.

With respect to specific geotechnical issues that cause change orders, Consultant A believes subgrade issues and difference in piling quantities are the most frequent and susceptible areas for change order occurrence. Consultant A suggested that such geotechnical change orders could be prevented through more careful site investigation through regular site visits, use of aerial maps, topographic surveys using the latest available technology and more extensive and calculated borehole drilling. As far as piling is concerned, he thought that cost overrun in pipe piles should be relatively less compared to say, H-piles. He also mentioned that the method of interpretation of the Standard Penetration Test (SPT) and Cone Penetration Test (CPT) data would have to be changed and viewed differently. As far as the Dynamic Cone Penetrometer criterion goes, the variations with chemically modified subgrade would have to be taken into account. He also specified that there should be a way for the geotechnical consultants to review their work after construction, to see in retrospect, how they could have done better with respect to their recommendations.

Consultant B

Consultant B was of the opinion that the reasons for geotechnical change orders could not be very different from those for change orders in any other work in construction. The very basic reasons for change orders, according to Consultant B, are time-related change orders (as time provided for completion of a work reduces, the work is done much faster and thus greater the number of change orders), weather-related change orders (weather is a factor that heavily affects change orders and this really cannot be controlled or worked around) and traffic-related change orders (maintenance of traffic during projects makes things much more difficult and leads to a lot more change orders being recorded). More specifically, the two most pressing issues with regards to geotechnical work, are:

1. Lack of subsurface information due to boreholes that are at fixed distances apart and do not accurately capture the soil profile at all places.
2. Variation of piling quantities due to selection of a wrong pile-type for a particular soil type.

Consultant B noted that in Indiana there is a strong preference for H-Piles due to its strength characteristics. However, he said the possible unsuitability of H-Piles to granular soils should also be considered, which is not done always. However, he also commented that it might be less expensive in most cases to deal with change orders rather than perform expensive pile load tests.

Consultant B believes that lack of communication between design to construction had to be a major reason for geotechnical change orders. He suggested that INDOT spent time and effort towards setting up a fool-proof communication system that left no gaps between the owners, geotechnical consultants, design consultants and the contractor. He indicated that many times what the geotechnical consultants prescribed was not taken into account by the design consultants and that what the design consultants recommended was not in the contract documents. According to him, in many occasions what is there in the contract documents and the geotechnical report is just unknown to the contractors. Consultant B also said that the lack of knowledge of site conditions on the part of the designer may result in minor glitches in design that cause change orders. He urged INDOT to have an established system and corresponding funding mechanism to enable designers to make more frequent field visits. Consultant B be mentioned that certain problems are obvious in the field, but are invisible in the office for the designers to be able to account for them in their design.

Consultant C

As we have repeatedly noticed in most of the interviews, Consultant C also emphasized on the problems of poor soils and mismatch in piling quantities. The need to identify poor subgrade soils and develop a sound methodology for piling quantities were the issues that needed immediate addressing as part of controlling geotechnical change orders, stated Consultant C. He identified the need to perform more intelligent and diligent site investigation with greater number of borings. He expressed the need to have a judgment-based decision on number of borings and pile driving, rather than going with fixed procedures. He indicated that the judgment needs to be backed by not only experience but also by knowledge of conditions in a particular area, even before any boreholes are drilled.

Consultant C very strongly recommended the need for a review system on INDOT contracts. This review system would have to allow geotechnical and design consultants to thoroughly revisit every part of their work and gauge their performance based on the events and quantities that were part of the construction process. In other words, Consultant C is of the opinion that geotechnical and design consultants need to be allowed to review their work by examining how accurate their recommendations were. He suggested that, for example, tabular summaries needed to be sent back to the consultants about the pile driving quantities that were finally used during construction. By comparing these with their recommendations, the consultants will then be able to zero in on the errors in their work. This would help them modify their approach in future contracts for specific soil types (e.g., underestimations/ overestimations from the PDA testing and the static and dynamic formulae used for interpreting test results could be identified and corrected in future projects). Consultant C also mentioned that with respect to the subgrade problem, the areas of soil that were eventually treated, the reasons behind treating them and the quantities involved could be sent back to the geotechnical and design consultants, so that they could rectify and remodel their approaches. Also, the contract information could be reviewed to see where the discrepancies arose during construction.

Consultant C also had a few other suggestions to make. He advised that in case of problems during construction, it might be better for the consultants who did the work initially to be called up, rather than INDOT trying to investigate and tackle the problem on its own. This would help because: a) the consultants should be in better shape to troubleshoot and tackle the issue as they performed the initial work, b) the consultants could learn from their mistakes and help in rectifying their errors on future projects, c) the consultants could send back recommendations to INDOT, which would help the latter tighten its provisions and specifications, shielding them from exploitation at the hands of contractors through change orders. For this, he recommended having an "open-purchase order for on-call construction problems" or something similar. Even without particular issues to be handled, Consultant C called for more active involvement of geotechnical and design consultants in the construction process in order to tackle the problem of geotechnical change orders.

In the next section, we summarize all the information and the important recommendations from the interviews.

6.4. Summary

In this section, we summarize all the important comments and suggestions that were made by the project engineers and the geotechnical consultants who were interviewed. Most of the interviewees mentioned that they did not see geotechnical problems to be the main contributor to change orders on projects. Also, they acknowledged the fact that the variability of soil is so great that it would be literally impossible to eliminate geotechnical change orders or point fingers at particular parties. However, they did recognize the need to address certain issues. According to the opinions of the various interviewees, the following were the main reasons that led to geotechnical change orders:

1. Failure to identify areas of poor subgrade soil:

   It was generally agreed upon that it would be impossible to identify all areas of poor soil. However, the interviewees mentioned that this is certainly an issue that cropped up very frequently and that subgrade treatment was the item that very often was part of change orders. Some of the main reasons for a change order concerning soil treatment were:

   a. Site investigation was not sufficient and problematic soils weren't always identified.
   b. Quantities were incorrectly calculated because incorrect elevations were given in the plans and, as a result, more soil than planned had to be treated.
   c. The volume of fill that the recycled pavement would cover was overestimated, when the usage of recycled pavement for filling undercut portions was prescribed.
   d. The prescribed soil treatment method was not the appropriate one for the particular site conditions.

2. Mismatch in Piling quantities:

   Again, all of the interviewees seemed to concur on the fact that pile driving quantities from the plan hardly ever matched the ones used in construction. Some of the typical reasons for change orders in piling were:

   a. The correct pile type, suited to the soil, was not chosen in the designs.
   b. The PDA tests, test pile driving and the static and dynamic formulae used for result interpretations tended to overestimate or underestimate pile quantities.

3. Erosion control:

   In erosion control work, the geotextiles and riprap quantities mostly overrun as their requirement is underestimated when there is no accounting for site conditions, such as insufficient right of way or soil drainage conditions. Quantities for geotextiles and riprap need to be more accurate as the problem of Errors and Omissions seems to be widespread in this case.

4. MSE wall construction:

According to the interviewees, change orders related to MSE wall construction are often encountered. Sometimes, when highways are widened, MSE wall configurations coincide with the drainage lines that run just outside the boundary of the existing highways. Often, the plans don't account for this problem and the specifications don't cover for such an issue either. This leads to several change orders as the issue is not considered in the planning stage. Also, ditches by the side of the old highways are often located in marshy soil, and plans do not cover for the treatment of soil in such areas.

Apart from the project specific change orders due to other reasons, the list above includes some very frequent reasons for change orders that were identified by the interviewees. Next, we provide a summary of the suggestions provided in order to improve on the geotechnical change order problem in INDOT contracts. The following is a list of suggestions provided by the various interviewees:

Recommendations for the subgrade treatment problem:

1. The site investigation should include a larger number of boreholes whenever possible. The approach to site investigation must also be very flexible and should vary depending on the soil type, the region of the state where the project is located and the pre-existing knowledge about the conditions prevalent at the site.
2. A procedure needs to be devised to calculate accurately quantities of recycled pavement for use in filling undercut sections.
3. Projects that are shelved over an extended period, long after initial site investigations were completed, need to have a secondary site investigation to verify that the conditions have not changed from the time of the initial site investigation.
4. There should be increased dependence on experience and technically-sound analysis and design as opposed to total dependence on specifications, since experience combined with quantitative assessments tend to account for specific conditions characteristic of each site as well as the region of the state where the project is located.
5. The method of treatment of poor soils should be selected based on type of soil.
6. DCP criteria should be included fully for quality control in all soils, with the criteria catering uniquely to each soil type.
7. On a particular contract, a record of all the areas where soil was treated and the related quantities need to be sent to geotechnical and design consultants in order for them to review their work and assess how accurate their recommendations were. This would help Consultants in improving their work for future contracts.

Recommendations for the piling quantities issue:

1. The pile type needs to be determined based on the type of soil rather than a preference for a particular pile type.
2. A tabulated summary of the piling quantities that were used during construction needs to be sent back to the geotechnical and design consultants - Since field piling tests and corresponding formulae tend to provide under or overestimations, this kind of review would help them to calibrate their future work based on an assessment of previous performance.
3. Better methods for assessment of pile capacity and interpretation of driving records should be developed so that in the future, methods that are capable of predicting pile quantities properly be used by INDOT.

General recommendations to tackle geotechnical issues causing change orders:

1. Undistributed quantities could be included in the contract at the time of bid to cover some expected geotechnical issues that are highly likely to occur.
2. Unit prices should be established against other bidders as these are normally more favorable to INDOT than establishing a unit price after the letting, with no other bidders being involved.
3. A check list could be developed including all possible problems, which could be used during the design process. This check list should be developed based on issues that occur repeatedly for a particular region or soil type or type of work.
4. The reason codes should be modified such that assigning a reason code for a change order is simple and devoid of any ambiguity - This would help future reference for determining influential problems causing change orders.
5. The right attitude towards change orders should be cultivated among one and all involved in the project. Apart from making INDOT staff and designers aware of the risk and cost of change orders, an effort should be made to develop an ethical understanding with the contractors.
6. Specifications need to be more solid in problematic areas like subgrade treatment and piling, without providing loopholes for exploitation.
7. Decisions on the methodology for managing changes need to be made really quickly because undue delay generally tends to increase the contract costs heavily.

The interviews helped us obtain a very practical and detailed view of some of the major issues causing geotechnical change orders. The suggestions will help INDOT narrow down on problematic areas, initiate possible modifications in these areas and also provide a base for determining methods to eliminate or manage these problems better. In the next chapter, we will combine the findings from the data and the interviews to look at all the results and recommendations in a holistic manner.

CHAPTER 7. RESULTS AND DETAILED RECOMMENDATIONS

7.1. Results

This study analyzed the problem of geotechnical change orders in INDOT projects through the following:

1. Literature review
2. Agency survey
3. Data collection and analysis
4. Interviews with relevant personnel

7.1.1. Results from the Agency Survey

The agency survey showed the relative standing of Indiana in comparison with some other states that provided data for this report (California, Georgia, Kansas, Kentucky, New Hampshire, Ohio, Virginia, and Wisconsin). As far as annual construction cost is concerned, Indiana stood medially in comparison with the other states that provided data for construction cost. Based on the results of the agency survey and the results from the descriptive statistics, the state of Indiana faired equally or in some years better than a couple of the other states that provided the geotechnical change order information for this report. Due to the lack of an exclusive database to store geotechnical change order information, several states were unable to provide relevant data. Compared to the states that provided geotechnical change order information for this report, the state of Indiana had about the same or lower percentages of annual geotechnical change orders. Even though the percentages seemed nominal, a minor reduction in change orders, to the extent that this would be possible, would result in substantial cost savings for INDOT. Also, through the agency survey, useful information was garnered regarding the frequent reasons for the occurrence of geotechnical change orders in various states. The results from the descriptive statistics and interviews indicate that the reasons for geotechnical change orders in other states are, in many cases, the reasons for geotechnical change orders in Indiana as well. The most prominent reasons for geotechnical change orders, as seen in the agency survey, are:

1. Unexpected site conditions due to insufficient site investigation
2. Design changes and errors
3. Changes in field conditions
4. Presence of man-made buried objects
5. Variation in contract items – payments and quantities

7.1.2. Results from Data Analyses

The results from the data analyses were discussed in detail in Chapter 5. The following are some important results obtained from the data analyses:

1. The average geotechnical change order amount per district per year was 1.34 percent of the total estimated construction cost per district per year.
2. The average geotechnical change order amount per district per year was 10.25 percent of the average amount of total change orders per district per year.
3. The average net overrun due to geotechnical change orders was $707,000 per district per year.
4. About 28 percent of the contracts that were considered in this study experienced geotechnical change orders. Out of the 300 contracts examined, 84 contracts experienced geotechnical change orders. In total, 158 geotechnical change orders were recorded in all the contracts.
5. Out of the 84 contracts that experienced geotechnical change orders, there were 64 road contracts, 16 bridge contracts and 4 resurfacing projects.
6. 46 contracts (out of the 84 contracts that underwent geotechnical change orders) experienced only one geotechnical change order, while 24 contracts experienced 2 geotechnical change orders.
7. About 41% of the total road contracts (155 contracts) experienced geotechnical change orders. About 37% of the total bridge contracts (44 contracts) experienced geotechnical change orders. The other contract types of this study's dataset were insignificant as far as geotechnical change orders were concerned.
8. Out of the 158 geotechnical change orders, Reason code 206 – Constructability: Soils-Related – was assigned to 101 geotechnical change orders. Reason code 405 – Changed Field Conditions: Soils-Related – was assigned to 46 geotechnical change orders. Reason code 108 – Errors and Omissions: Soils-Related – was assigned to the 11 remaining geotechnical change orders. When compared to the total number of items that underwent change due to Errors and Omissions in all change orders (637), the occurrence of errors and omissions in geotechnical change orders is relatively low, which is a positive sign.

7.1.3. Results from Interviews

Most of the interviewees mentioned that they did not see geotechnical problems as the main contributor to change orders on INDOT projects. Also, they acknowledged the fact that the variability of soil is so great that it would be literally impossible to eliminate geotechnical change orders or point fingers at particular parties. However, they did recognize the need to address certain issues. According to the opinions of the various interviewees, the following were the main reasons that led to geotechnical change orders:

1. Failure to identify areas of poor subgrade soil

   It was generally agreed upon that it would be impossible to identify all areas of poor soil. However, the interviewees mentioned that this is certainly an issue that cropped up very frequently and that subgrade treatment was the item that was very often part of change orders. Some of the main reasons for a change order concerning soil treatment were:

   a. Site investigation may not have always been sufficient, and problematic soils weren't always identified.
   b. Quantities were incorrectly calculated because incorrect elevations were given in the plans and, as a result, more soil than planned had to be treated.
   c. The volume of fill that recycled pavement would cover was overestimated in places where use of recycled pavement, for filling undercut portions, was prescribed.
   d. The prescribed soil treatment method was not the appropriate one for the particular site conditions.

2. Mismatch in piling quantities

   Again, all of the interviewees seemed to concur on the fact that pile driving quantities from the plan hardly ever matched the ones used in construction. Some of the typical reasons for change orders in piling were:

a. The correct pile type, suited to the soil found at the construction site, was not chosen in the design.
b. For a given pile capacity, the pile length was not correctly estimated.

3. Erosion control

In erosion control work, overruns occurred often for geotextiles and riprap quantities as these were underestimated when there was no accounting for site conditions, such as insufficient right of way or soil drainage conditions. Quantities for geotextiles and riprap were inaccurate due to the problem of errors and omissions.

4. MSE wall construction

According to the interviewees, change orders related to MSE wall construction were often encountered. Sometimes, when highways were widened, MSE wall configurations coincided with the drainage lines that ran just outside the boundary of the existing highways. Often, the plans did not account for this problem and the specifications did not cover for such an issue either. This led to several change orders. Also, ditches by the side of the old highways were often located in marshy soil, and plans did not cover for the treatment of soil in such areas.

7.2. Detailed Recommendations

7.2.1. Recommendations from the Study

Based on the analysis of the data and the interviews conducted, with various INDOT engineers involved in the contracts and geotechnical consultants, this study makes the following recommendations in order to reduce the occurrence of geotechnical change orders on INDOT contracts:

1. The right attitude towards change orders should be cultivated among one and all involved in any given project. Apart from making INDOT staff and designers aware of the risk and cost of change orders, an effort should be made to develop an ethical understanding with the contractors.
2. Since it is seen that contracts with large budgets undergo more change orders, particular attention needs to be given at the planning stages, especially for these contracts. The following measures may be given consideration:

   a. Experts need to be consulted to evaluate risks accurately and, as appropriate, funds need to be reserved based on the estimated risk level of the project
   b. Geotechnical work must be allocated time and financial resources that are consistent with all design documents.

3. A check list including all possible problems could be developed for use during the design process. This check list should be specifically developed based on issues that occur repeatedly for a particular region or soil type or type of work.
4. The system of reason codes should be modified such that assigning a reason code for a change order is simple and devoid of any ambiguity. This would help future reference for determining influential problems causing change orders.
5. The geotechnical report should not only identify all existing problems but should also discuss the possible courses of remedy for the issues.
6. Change orders should be routed through the geotechnical office so that the designer is made aware of the occurrence and reason for the change orders.
7. A clear analysis of all geotechnical specifications needs to be carried out to identify specifications with potential for exploitation by contractors.
8. The geotechnical engineer should coordinate with design and district construction personnel while making recommendations.
9. More caution needs to be exercised during the planning and bidding of road contracts since the data analysis showed that the road contracts were the most affected by geotechnical change orders, mainly due to the length of these projects (change in site conditions are more likely to occur). Contractual agreements may be introduced to allocate some risk to the contractor in the case of road projects.
10. In road contracts, especially in urban areas, the load applied by the construction traffic on the bare subgrade should be accounted for during the design stage.
11. Possible constructability issues that may arise due to soil-related reasons need to be better predicted at the planning stages since the maximum number of geotechnical change orders was due to soil-related constructability issues, as shown by the data analysis. A database of all constructability issues that occur could be developed to narrow down and better handle frequently arising constructability issues. The district, central and geotechnical office need to get together to perform a detailed constructability review, prior to letting of major roadway projects. Especially, traffic regulation and factors that can affect the quality of subgrade must be assessed from a constructability viewpoint.
12. Designers need to be aware of geotechnical foundation information, especially with respect to conditions below the subgrade so that they can include relevant items in the contract documents.
13. Field conditions need to be more accurately assessed in order to reduce the number of change orders due to changed field conditions. More resources may be allocated towards site investigation for large projects, with greater level of flexibility in approach and budget.
14. A flexible approach to site investigation based on soil type, region of the state, and pre-existing knowledge about prevalent conditions at a site needs to be taken whenever possible. Additional borehole-drilling should be performed wherever preliminary data indicates the possibility of variable soil conditions – In problematic areas the preliminary investigation should be followed by a more rigorous secondary investigation.
15. Projects that have been shelved over long periods of time need to have a secondary site investigation performed before construction starts so that *in situ* test results obtained from the preliminary site investigation can be reevaluated. Specifications need to be devised for doing this.
16. The problem of variation in moisture content, between the time of site investigation and the time of construction, should be tackled.
17. Borings for rock excavation need to be performed at accurate locations, to avoid change orders due to varying

elevations of the rock layer. More effort should be concentrated towards evaluating the quality of rock, as there is a tendency to neglect detailed classification of rock types.

18. More attention must be focused towards determining piling quantities accurately and suitable research could be conducted in this area.
19. When anomalies are encountered during construction, a second geotechnical investigation should be set up and the district, central and geotechnical offices should get together to recommend a suitable solution, rather than direct implementation of specifications in all cases. Also, the changes due to geotechnical reasons need to be primarily evaluated by the geotechnical office.
20. An effective software system needs to be developed to comprehensively record change order information, immediately after change orders have occurred – This would help in future assessment of change orders (Considerable amount of time was lost in this study in manually creating a dataset from contract documents).

7.2.2. Recommendations from Interviewees

The following recommendations are some recommendations made by the interviewees:

1. The following should be kept in mind in order to decrease the number of change orders associated with subgrade issues:

   a. The best method of treatment of poor soils should be selected. This decision should take into account the types of soils found at the project site. Whenever possible, DCP criteria specific for each soil type should be developed and used for compaction quality control.
   b. On a particular contract, a record of all the areas where soil was treated and of all the related quantities needs to be sent back to geotechnical and design consultants in order for them to review their work and reassess how accurate their recommendations were. This would help consultants improve their work in future contracts.

2. The following should be kept in mind in order to decrease the number of change orders due to issues related to piling quantities:

   a. The most appropriate pile type for particular soil conditions must be chosen (the practice of using mostly a particular pile type for convenience reasons should be eliminated).
   b. A tabulated summary of the piling quantities that were used during construction needs to be sent back to the geotechnical and design consultants. This would help them make adjustments at the planning stage on future projects.
   c. For a given pile capacity, the pile length needs to be predicted more accurately. Efforts need to be made to improve the accuracy of analysis of results of PDA tests that are widely used on INDOT projects.

3. Specifications need to account for handling of pipelines and marshy soil that coincide with MSE wall configurations planned during expansion of roads.

CHAPTER 8. RECOMMENDATIONS AND CONCLUSION

8.1. Recommendations

In the previous chapter we saw in detail, the recommendations and inferences from this study. The following are the main recommendations from this study in summary:

1. The correct attitude of preventing change orders, rather than dealing with them, needs to be developed among one and all.
2. Reason codes for every change order have to be formulated free of ambiguity.
3. The geotechnical report must not only identify all problems but should also provide a discussion of all possible solutions to the geotechnical issues on the project.
4. For large projects, site investigation must be extensive and flexible, suitable to the particular soil type/region of state, to avoid subgrade treatment problems. In areas of problematic soil, the preliminary investigation should be followed by a secondary investigation with more number of boreholes.
5. The geotechnical engineer should coordinate with the design and district construction personnel while making recommendations.
6. Change orders related to geotechnical work should be routed through the geotechnical office so that the designer is made aware of the occurrence and the reason for the change orders.
7. Detailed constructability reviews, with the participation of the geotechnical office, must be conducted before the letting of major projects. Especially, traffic regulation and factors that can affect the quality of subgrade must be assessed from a constructability viewpoint.
8. Designers need to be aware of geotechnical foundation information, especially with respect to conditions below the subgrade so that they can include relevant items in the contract documents.
9. Impact of construction traffic in urban settings, needs to be accounted for in design.
10. Variation in moisture content from site investigation to construction should be accounted for in design.
11. Specifications need to be evaluated for constructability, before implementation.
12. Rock excavations must be accurate and the quality of rock must be well examined.
13. Shelved projects need to have a secondary site investigation. Anomalies during construction should also be sorted out through a second site investigation, with involvement of the geotechnical office.
14. More attention must be focused towards determining piling quantities accurately and suitable research could be conducted in this area.
15. An effective software system needs to be used to record change orders.

8.2. Conclusion

Despite relatively low percentages of geotechnical change orders reflected by the data analysis and the fact that interviewees generally felt that geotechnical change orders were not the major cause for change orders on most INDOT contracts, a concerted effort should be made towards reducing geotechnical change orders. This would result in significant cost savings for INDOT. The basic recommendations from this study would be a good place to start for preventing or managing geotechnical change orders better.

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