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Is the owner receiving full value for the cost of site exploration?

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ABSTRACT:
Experience fails to indicate that an abundance of exploratory data or high-tech resources utilized during the design process have effectively diminished cost and time overruns. Albeit more exploration data is gathered, design summary reports are issued, and site investigation "database" is continually expanding, the results have changed little. Consequently, due to time constraints at the time of tender, the mass of exploratory information remains underutilized. Unless the exploratory data is presented as a cohesive, consistent, and complete geological, geotechnical, and design package, it cannot reduce project risks or costs.

Not uncommonly, design has been inconsistent with practical and efficient construction realities. These inconsistencies are guaranteed to increase costs and delays.

This paper does not propose new techniques, practices, methods, or computer programs. We simply suggest that the industry develop a more universal and independent point of observation that focuses on the owner's concern, satisfies design requirements, provides more specifically for construction needs, and reduces risk, delays, and cost overruns.

1 INTRODUCTION

When underground projects encounter difficulties associated with geotechnical conditions, inadequacy of exploratory information is often blamed. In spite of more sophisticated and costly site exploration, there have been no proportional decreases in delays and cost overruns.

The *"we need more information"* recommendation is too easily proclaimed without a clear conception of:

- the precise contribution the additional data will provide to a better understanding of anticipated behaviour,
- how it will be used to produce more certainty, less risk, and cost savings (other than a higher comfort level),
- the effect it will have on the current uncertainty (the presumed cause of need for additional information), and
- whether it will and how it will influence or change any decisions that can already be made without the additional data.

The need for additional information cannot be justified by uncertainty. It must be justified by resolution of uncertainty.

The need to know anticipated conditions in underground construction must be defined in the dimension of space (and time) and how the material will behave in that space when disturbed. In other words, where will conditions be encountered and how will they behave.

Conventional exploration generally produces a database of measurable or definable characterizations of the geological medium. Most and nearly all exploration data deal with intact and rock mass characteristics. Characteristics provide no inherent indication of how materials will behave. Behaviour of the natural medium must be interpreted.

Although project exploratory data has grown in volume and cost, the quantity and quality of professional interpretations (opinions) of actual behaviour has not, in spite of the preparation of "design summary reports". Design summary reports are insensitive to day-to-day construction behaviour and fail to address crucial construction issues and are misleading in the assessment of construction conditions because design can accommodate a greater variation in conditions than the construction process, particularly in terms of excavation progress. Variations in progress have considerable large economic consequences.

The time spent by the engineer to explore the site, establish anticipated conditions for design, design the structure, and prepare bid documents, is at least an order of magnitude (years) greater than the time available to the contractor (months) to prepare an estimate. Consequently, what is not accomplished prior to tender cannot be expected of the tendering contractors.

2 PRE-EXISTING CONDITIONS, CONSTRUCTION PROCESS, AND GROUND RESPONSE

"*Geological conditions*" are generally considered to define characteristics of the natural materials. "*Tunnelling conditions*" have been used to define the effects that the geological conditions have on tunnelling operations. This is a fundamental and gross fallacy associated regarding geological conditions and tunnelling conditions. The danger of this gross misconception is a failure to understand the process and conditions associated with pre-existing conditions and construction interaction.

Since "geological conditions" pre-exist even site selection, one must accept site conditions as independent and pre-existing variables. One can only explore geological conditions, interpret the information, and apply it to minimize adverse consequences of man's construction activity. With that established, it becomes clear that any disturbance of, within, with, and around pre-existing natural materials can have a variety of consequences. However, it must be stressed, that *behaviour* of natural materials can only be observed when subjected to some external force, disturbance, adjustment of existing forces, or conditions. Pre-existing conditions are inanimate and cannot produce consequences unless they are disturbed.

Behaviour of natural materials, given pre-existing conditions, disturbance by changes in the state of stress, using various methods, equipment, and resources can only be defined as a "*response*", or more specifically a "*ground response*". Use of the term ground response makes the distinction that it requires an external stimulus, such as the removal of material to create a hole in the ground. How the hole is created and the subsequent measures to minimize, eliminate, or mitigate the effects of the disturbance will have a consequence on ground response. Disturbing a set of pre-existing inanimate conditions, with any particular construction activity, will have relatively predictable consequences. It is the chosen means of disturbance that has the greatest impact on the outcome, consequence, or effect that are often unjustly blamed on the geological conditions.

The impact of ground response is invariably measured or noted as *construction response*. However, there is no direct or exclusive connection between geological conditions and construction response, the intermediate means of disturbing the equilibrium with the construction system first produces a ground response, which can, only then produce a measurable consequence in construction response (performance).

An understanding of the ground response concept effectively shifts the cause to the manner of construction disturbance rather than the pre-existing condition. That understanding forces a shift in exploration as well as selection of the ultimate construction method by the engineer and contractor.

3 PERSPECTIVES

The perspectives of the parties vary considerably and account for some of the inherent construction difficulties. These difficulties may be identified simply as:

- inadequate data to eliminate contingencies
- parochial use of existing available information,
- cost overruns, especially beyond available budgets,
- delay of project completion, and
- adversary relationships.

3.1 The Owner

The owner has to communicate a desire for the construction of a facility with associated conditions and with specific requirements, to a series of professionals who have the task of coordinating their efforts in developing plans and contract specifications between the owner and the lowest tendering contractor.

The owner is interested in:

- having a completed facility which will perform its intended function,
- at the lowest possible cost,
- within a strict budget,
- with no risk, and
- on schedule.

The owner's dilemma consists of relieving contractors from the obligation of performing their own testing or padding the bids to cover unfavorable subsurface conditions, when "representing" or "indicating" what contractors can expect to encounter, thus exposing the owner to liability for extra costs or time delays. The owner/engineer must consider the cost/benefits of:

- various levels of exploration,
- presentation of geotechnical data,
- interpretation of data, and
- use of exculpatory clauses.

Underground construction has inherent risk associated with it. Consequently, the owner attempts to limit exposure by protecting themselves through contract language and by not providing interpretive or explicit site data. The owner has the upper hand since he is the party who generates the contract documents. Public officials consider a harsh contract with broad exculpatory clauses their only protection against the contractor, who is often viewed as the enemy. Such contracts and exculpatory clauses have generally been ineffective, produced mistrust, and have generally been detrimental to the utilization of underground space.

The degree of risk is directly related to the contractor's perception of anticipated conditions, degree of certainty, and perceived risk. Presentation of borings, boring logs, test results, and broad exculpatory narratives is no longer considered state-of-the-art or for that matter, acceptable.

Risk is related to how well anticipated conditions and ground response are defined when it is disturbed through construction processes. Exploration merely defines characteristics of the material and not the behaviour of the material during construction. The return on investment of costlier exploration may not be realized unless more progressive techniques are used to present data specifically designed to impart quantitative perception of ground response for construction estimating.

It is the engineer's responsibility to illustrate effectively to the client (owner) the relationship between cost and benefit of site investigations, interpretation, contract terms to address unanticipated conditions and risk, and the benefits of equitable allocation of risk.

There are countless underground projects where risk, by design, was reduced and limited. However, this can only be accomplished in the initial stages of project development with the initiative and support of the owner. The use of Boards of Consultants was one such method. However, these boards are used less frequently than in the past. Perhaps, false complacency or "not invented here" attitudes regarding site investigation, engineering design, and project construction has contributed to the failure to better utilize specialists, boards, and consultants.

3.2 The Engineer

The primary objective of any business enterprise is to make a profit and it is unrealistic to assume that an engineering company is any different. A primary profit motive relegates the best interests of the owner to a secondary priority. On several projects, consultants to the owner and boards of consultants, have successfully implementing major conceptual, design, and construction changes that have resulted in substantial savings in time and cost and have reduced risk.

Engineering companies are generally sought to provide services during various stages of a project, namely to establish feasibility for basic design, develop exploration, prepare a final design, prepare for tendering, and inspect construction. At each stage the associations, objectives, and responsibilities vary.

Initial feasibility studies and site investigations have the greatest influence on reducing construction costs. However, site investigation are implemented primarily for design and may be insensitive to the needs of the contractor in terms of:

- geotechnical conditions,
- site characteristics,
- behaviour of natural materials, and
- what is necessary and how it is used to prepare a construction estimate.

Site investigation data that fulfill design considerations generally do not satisfy the needs of construction.

The engineer reflects, for the most part, the attitudes of the owner. In addition, engineers inevitably act from their own financial concerns, risk, and liability. Not uncommonly, these may be contrary to project costs.

3.3 The Contractor

The contractor's needs are relatively simple yet not easily satisfied. He need only to answer the questions:

Who, What, How much, Where, and When ?

- Who is responsible for What ?
- What will be encountered ?
- How much of it will there be ?
- How will it behave ?
- Where will it be encountered ?
- When will it be encountered ?

There is usually a:

- vast amount of data to digest,
- only limited time available during tender,
- a high level of geotechnical expertise required to interpret anticipated behaviour,
- need for behaviour under construction conditions, and
- they must all be quantified for the construction estimate.

All has to end up in quantitative terms with specific costs assigned to each item. This process can be accelerated with quantitative, graphical, and clear presentations of site investigation data.

4 PRE-EXISTING GEOTECHNICAL CONDITIONS

Pre-existing geological conditions are classically defined by general information such as regional geology, structural geology, rock lithology, etc. More specific data is also provided in the form of boring logs, sample descriptions, material descriptions, various index properties, and test results. These, however, must be interpreted to determine how the material will behave in response to the construction activity.

4.1 Geotechnical Data

Most commonly, site investigation data is simply provided, often in geotechnical reports as part of or as a supplement to the specifications. What to do with such a database? In most cases, interpretation of data is avoided to evade liability or the inability to translate anticipated conditions into a day to day ground response necessary for the preparation of a construction estimate.

4.2 Summarizing Anticipated Conditions

Since selection of construction methods, equipment, and planning rely on the average and range of conditions anticipated, they must be defined in those terms. The construction system is selected to produce the highest possible excavation rates under average anticipated conditions, high progress under the anticipated range of conditions, and also deal with the most adverse conditions within acceptable yet reduced progress, without necessitating changes to the construction scheme.

A minimal presentation should provide a summary of data by geological units, for the entire project, or by the most appropriate grouping. The most typical summaries of anticipated material characteristics is usually tabular, reporting data for each test or consisting of a summary table of all properties of a single geological unit. Such methods do not produce a self evident representation of material characteristics in the mind of someone preparing a construction estimate. A more effective portrayal of rock properties may be accomplished using quantitative and graphical means. The recommended presentation should include the full range and the average properties, characteristics, and typical ground response characteristics.

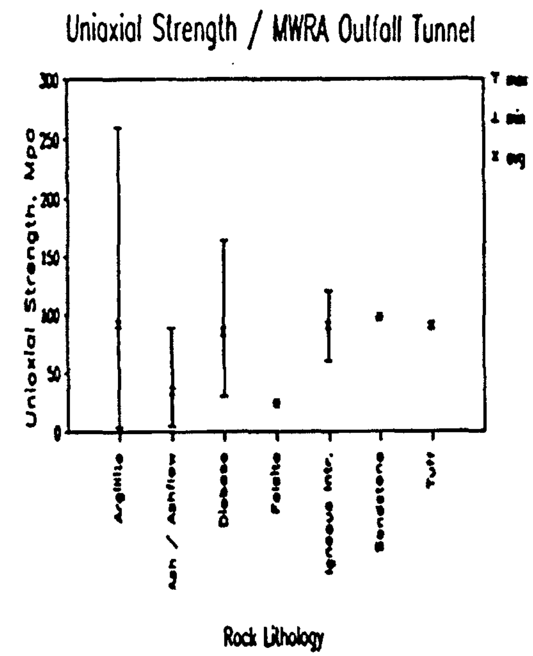

FIGURE 1: SUMMARY OF GEOTECHNICAL PROPERTIES (By Lithology)

An example of a summary of anticipated conditions is illustrated in *Figure 1*. Summaries may show material ranges and averages of material properties by type or simply by frequency of distribution in various strength ranges for all anticipated materials.

Interpretation of the geotechnical database (regional geology, structural geology, geophysics, borehole logs, samples, tests, and any other forms of information useful in predicting anticipated conditions and construction behaviour) is the domain of the geotechnical engineer. The detail and rigour with which interpretations are generally made for design, are inadequate and unsuitable for preparing a construction estimate. Does it make sense for the engineer to merely collect the data and leave it to the lesser qualified contractor for interpretation?

4.3 Interpretation of Anticipated Behaviour

Interpretation should be made utilizing either established standard practices appropriate to project conditions or other reasonable methods that can be justified. Some examples of reasonable methods, are:

- Q-rating of the rock mass,
- Rock Mass Rating System (*Figure 2*),
- Rock Quality Rating System (*Figure 2*),

There may be other tunnelling or construction behaviour to be determined that is not defined by standard methods or known reasonable methods. These should be defined by reasonable assumptions, reasonable speculation, or interpretation. An example of such reasonable speculation is the requirement for panning of water during concreting of the tunnel. The engineer may provide their estimate of the quantity of panning required or provide simple assumptions and calculations to assure some consistency among tenderers.

Since the overwhelming consequence of the fear of liability, risk, and limited ability to define ground behaviour sensitive to construction conditions results in an avoidance of interpretation or effective interpretation, alternatives may be examined. One of these alternatives is a comprehensive presentation which includes geotechnical characteristics, results of accepted or standard analyses for ground classification, and projection of conditions and ground classifications over the project alignment.

4.4 Comprehensive Presentation of Anticipated Conditions and Behaviour

What if a presentation could be made that avoided interpretations and presented only anticipated conditions and ground classifications along the alignment? Such a comprehensive presentation would illustrate the raw data available along the alignment, portray it graphically making adverse ground conditions immediately apparent, and allow projection of conditions over the tunnel alignment, section by section.

Each section would be defined by mid-points between borings, formation boundaries, major changes in characteristics, or other factors that would make the section unique. The presentation may be color coded to reflect advantageous or adverse conditions, allowing a simple visual examination to provide a conception of the magnitude and extent of the variation of conditions. An example of such a presentation is illustrated in *Figure 2*. The profile would normally be prepared in color to accentuate adverse conditions in the warm colors (red, orange, yellow) and attenuate the favorable conditions with cool colors (blue, green).

A comprehensive presentation should include:

- provide a summary of anticipated conditions,
- provide a summary of anticipated construction behaviour,
- provide a single drawing, preferably a plan and profile, showing all data, and
- interpret and reference the geotechnical database.

The presentation will provide:

- a self evident representation conducive to a clear perception of the distribution of geotechnical conditions over the space occupied by the structure to be excavated,
- interpretations limited to narrow spread.

Since geotechnical properties and descriptions merely characterize the medium of tunnelling and fall short of predicting actual behaviour, an interpretation is necessary for preparing a construction estimate. The summary of anticipated behaviour may also be summarized along the length of a profile. For example, the engineer provided anticipated rock mass rating and anticipated water conditions along the tunnel and these were included in the profile shown in *Figure 2*. In addition, as noted in *Figure 2*, it is possible to add additional data, such as anticipated support types, excavation performance, or TBM performance as noted in *Figure 2*.

5 RECONCILIATION OF LOCAL EXPERIENCE

In many respects, local underground construction experience can perhaps be even more enlightening than anticipated conditions. This is true because the experience does not so much reflect abstract conditions as reflecting actual behaviour under construction conditions. There

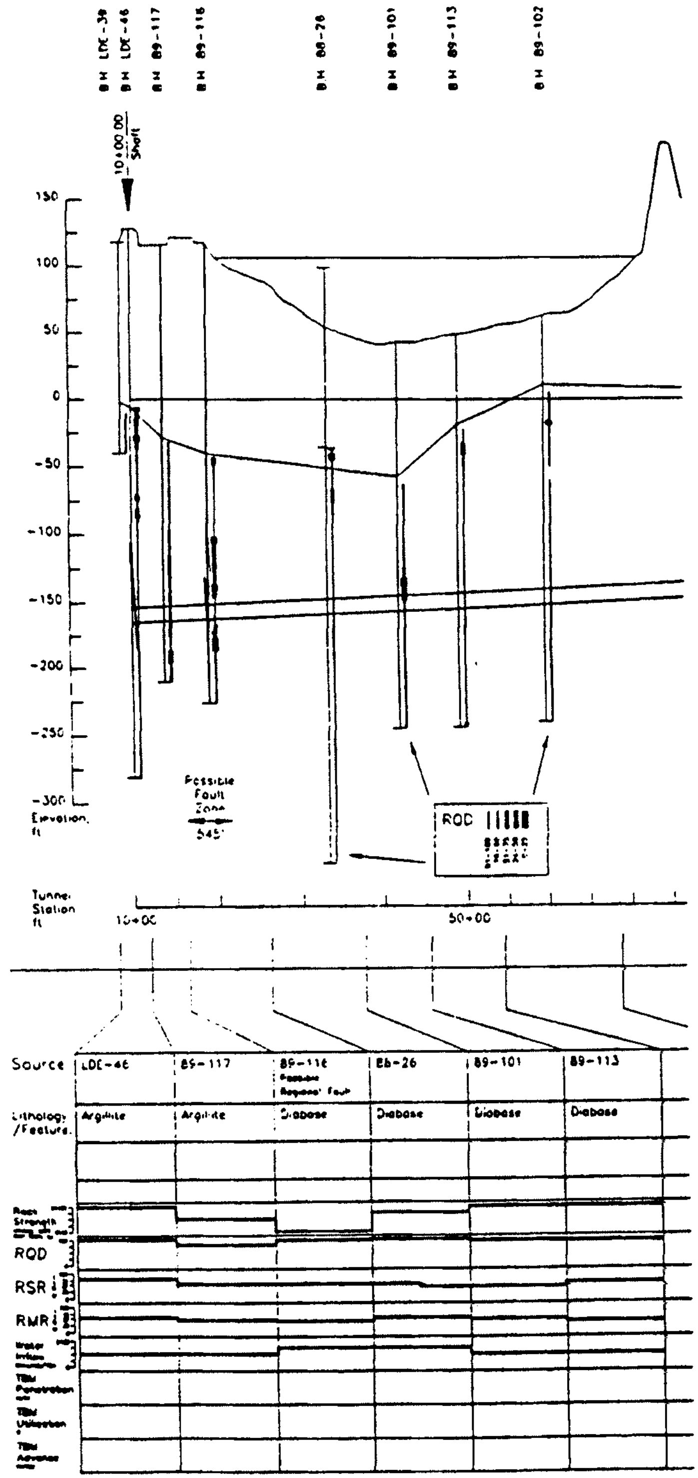

FIGURE 2: ANTICIPATED GEOTECHNICAL AND TUNNEL CONDITIONS

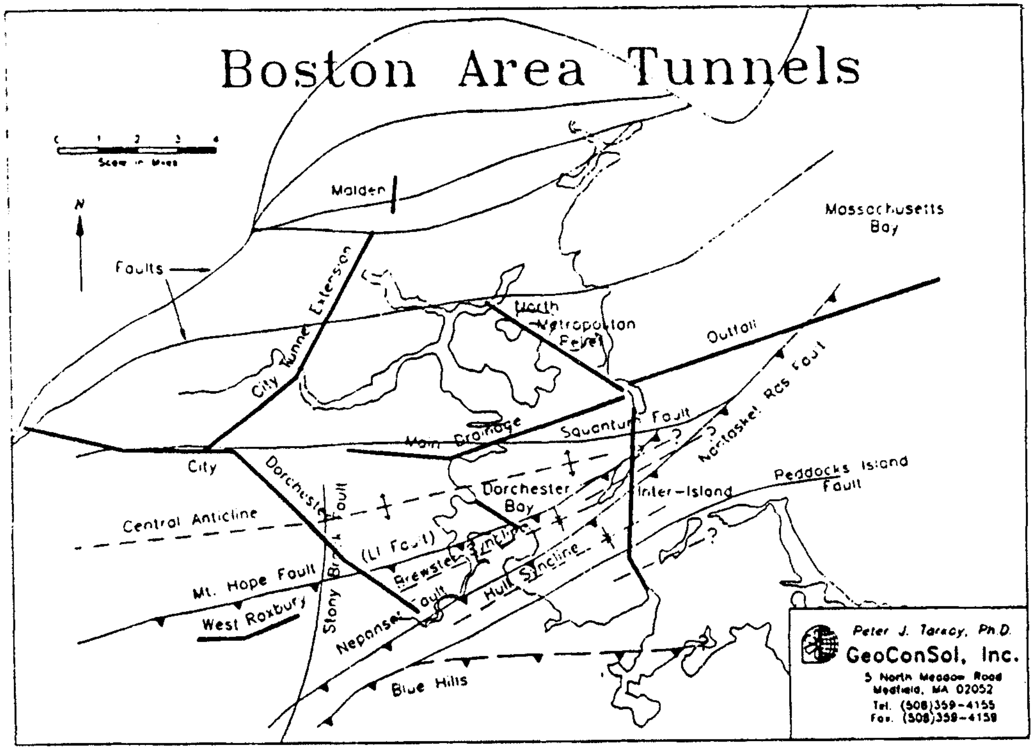

FIGURE 3: SUMMARY OF TUNNELLING EXPERIENCE IN BOSTON

are three fundamental considerations to remember.

The first, is that past experience has to be viewed or reviewed within the current environment or state-of-the-art of the industry. In other words, past experience should not be "copied" or "expected" unequivocally to apply today. This is true for several reasons. The past should be considered as a starting platform for future accomplishments, and should not be viewed as a goal. Since the technology has progressed, past experiences do not apply directly. In some cases, these experiences can be improved (e.g.- excavation rates using TBMs). In other instances, improvements in technology have produced entirely new problems to solve. For instance, the use of mechanical excavation has resulted in high advance rates. The contractor's coordination and the capability of the backup system to keep up with these high rates are often strained and consequential progress suffer with results less than anticipated because of excavation rates higher than foreseen.

Secondly, the experiences must be broken down into the lowest common denominator to be applied in a systematic, useful, and quantitative manner. Geological conditions, the construction scheme, construction coordination, the excavation and backup systems all play major roles in overall construction performance. If any of the components of past experience are at variance with the current project, they may still be used if the elements can be selectively applied.

Experiences should be distilled so that they can be applied to a new project, excluding effects of features that are different.

Thirdly, analyses which allow such experiences to be usable, must be prepared prior to the tender since the normal time available to prepare an estimate and the expertise of the contractor is not conducive to the best and most effective interpretation, evaluation, and utilization.

One such example is the effect of rock mass structure on specific tunnel alignments. In one case, all NE-SW trending faults, except for a regional fault, were indiscernible or relatively inconsequential when encountered in several tunnels. In some cases, these faults were mapped only as a single plane when encountered in the tunnel. However, a N-S trending fault in one of the tunnels affected rock mass competence, tunnel stability, and required tunnel support over a length of 500 meters.

Although 7 of the 8 tunnels had been mapped in detail and described in published papers, no practical compendium of experience, applicable to future projects, had been developed. For example, it was not possible to determine the reason that tunnels in the same rock lithology required enormous variations in support. The engineer had provided a generalized explanation for this phenomena, however, without firm evidence and a rational analysis to support the conclusions, it remained a mere speculation.

Figure 3 is a plan map of the Boston Harbour Area where 8 tunnels were excavated, most in the 1950s. All the tunnels were excavated by drill and blast methods except for a short portion of one tunnel that was started with a TBM. The tunnels cross the local structure (bedding, jointing, and faults) at various angles. The experience indicates that these tunnels required anywhere between 0.1-100% percent steel rib support. Furthermore, the effect of encountered faults on requiring tunnel support ranged from 0-500 meters. Some faults were mere traces, barely discernible or inconsequential in terms of tunnel stability and support. With such variations in support and effect of faults on tunnel stability, some interpretation prior to tender would have provided considerable enlightenment and reduced inevitable contingencies.

An example of a cursory attempt at integration of past tunnelling experience is illustrated in *Figure 3*. The example portrays the reconciliation of regional geology, structural geology, and lithology to selectively apply appropriate tunnelling experience to anticipated behaviour for the tunnel being bid.

6 THE ROLE OF CONTRACT DOCUMENTS AND SPECIFICATIONS

Contract specifications are simply to bind the two parties in an agreement that will produce the results for which the owner contracted.

The contract and associated documents are the only opportunity for the owner and engineer to convey their perception of project conditions. If project conditions are not fully, exclusively, and quantitatively conveyed at this stage, the relationship cannot be amended at a later time. It is like the marriage vows, "speak now or forever hold your peace."

It is not uncommon for engineers to assert that some of the encountered conditions should have been anticipated. This of course is uttered exclusively in hindsight and is considered in poor form if not documented in the preconstruction data.

7 REFERENCES

Tarkoy, P.J. (1991). Geotechnical Conditions Anticipated in the Inter-Island Tunnel, Boston, MA, Report, 25 February.