

PREScriptive SPECIFICATION DESIGN: THE IMPACT ON COST AND CONSTRUCTABILITY – CASE HISTORY

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ABSTRACT

This paper outlines how specification driven design has made Toronto Area transit infrastructure projects more expensive than similar private projects, and provides a case study of the results of an excavation at Launch Shaft 1 (LS1) for the Eglinton Crosstown Light Rail Transit project in Toronto, Ontario. The paper will describe the impact specification driven design parameters can have on design economy, constructability, and schedule and will suggest an alternative approach utilizing the Observational Method. As a result of the initial specification based design, Isherwood was retained by both the General Contractor and the Specialty Excavation Shoring Contractor to provide value engineering leveraging the Observational Method to improve constructability and construction schedule. By using well known, accepted design methods coupled with local experience in lieu of the specified design pressures and parameters, the redesigned bracing scheme reduced construction cost and schedule. This excavation case history can be a lesson learned for future transit projects.

Keywords: specification, risk, constructability, schedule, Observational Method, shoring, excavation

The City of Toronto has been developing its transportation network since the mid 1800's. "Canada's First Subway" along Yonge Street opened in March 1954 (TTC 1954), with a few additions to the subway network through to the 1980's. The following two decades marked a long period of slow development due to recessions, budget cuts, and politics along with several cancelled projects. To fill the gap left by years of underfunding, several new transit projects are now under construction in the city as a part of Metrolinx's \$50B, 25 year, "The Big Move" initiative (Metrolinx 2013). The work on these types of infrastructure projects is highlighting a different and developing challenge within the tendering and design specification structure we will call Prescriptive Specification Design (PSD).

PSD is a method used within contract specifications to control design risk on a project by applying conservative design methods, factors of safety, or other parameters to make a "*fool proof*" design. It is akin to requesting a colouring by numbers approach from a painter. There are inherent risks of using this method of tendering a project including increased project costs, longer construction schedules, and decrease of overall project economy. In PSD, the Owner "owns" all of the design risk on a project, including any additional costs due to changed site conditions. However, the Contractor commonly "owns" the risk of any deviations from the design specification they pursue, therefore making any improvements to the design, cost, or schedule less desirable from the Contractor's point of view. The impact of this type of strict specified approach to design has been seen in transit infrastructure projects in the Toronto area. Figure 1 outlines the range of specified AEPD design pressures as a function of excavation height (H) specified for use in Toronto underground transit projects since the 1970's to present day. A clear trend can be seen with respect to increased design pressures specified. The ranges shown for each project are intended to account for the potential differences in soil conditions for the highly overconsolidated

glaciated soils in the Toronto area. The graph also highlights the typical range, in blue, for the industry practice in Toronto for comparison.

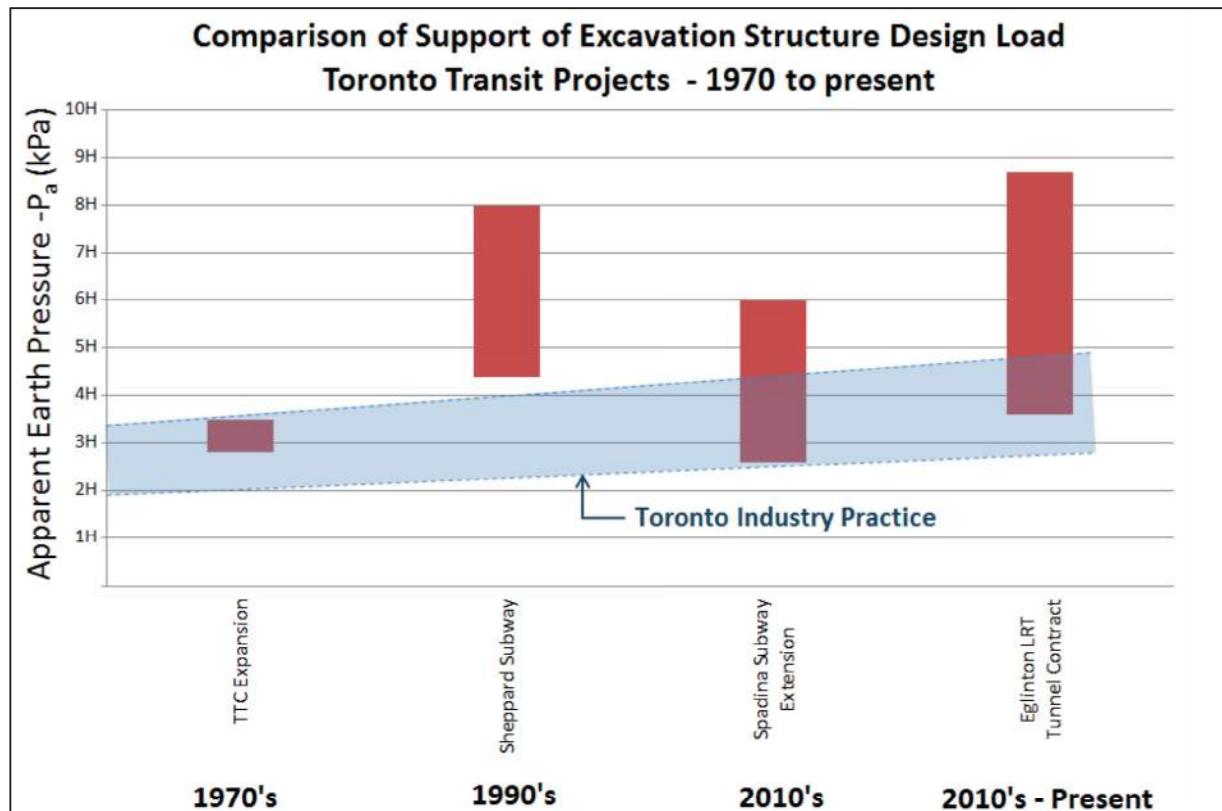


Fig. 1. Comparison of Design Loads of Transit Projects in Toronto from 1970 – Present

The subsurface work component of most projects represents the highest project risk with respect to time, cost, and liability. There is uncertainty with respect to the project geology, uncertainty in the geotechnical investigation, and uncertainty of the soil classification. It is important to note: uncertainty can also create opportunities within design.

RISKS WITH THE PSD APPROACH

There are a variety of risks with the PSD approach to projects, which increase in scale with the size of the project. Conservative or “heavier” design approaches lead to increases in material costs due to larger structural components, and manpower costs from increased installation time, material handling, and assembly. Large projects requiring large teams tend to involve international experts without the knowledge of the local construction environment and local soil conditions, understandably leading to more costly and conservative designs. In contrast, private projects with more flexible management systems leverage local knowledge to achieve lower project costs.

Another observed negative side effect of the PSD approach is the fixed mind-set of site personnel on projects viewed to be “conservatively designed” (Dweck 2007). On public infrastructure projects designed more conservatively than their equivalent private project counterparts, this conservatism is apparent to workers (comparing pile sizes, rows of anchors, etc.) and the “it’s overdesigned” mentality can be pervasive. In our experience, this manifests in a variety of ways including: over excavation past support levels, use of shoring supports for secondary support purposes without proper review, construction activity damage to the shoring structure, less emphasis paid to timely or accurate monitoring of shoring and neighbouring structures, and less general respect paid to design restrictions. The increased

quality assurance and control programmes typically seen on infrastructure projects can somewhat balance the risk of this, however the presence of this mentality presents a risk as some components on a project are critical no matter how conservatively designed.

Using the PSD approach discourages creativity in choice of design and construction methods outside of those specified due to lack of an effective risk or cost-savings sharing mechanism for these alternatives. This leads to missed opportunities due to over commitment to the PSD approaches early in the projects leaving absent analyses of alternatives, and leading to increased commitment in later project stages (Flyvbjerg 2014). In these cases, the Owner is typically paying for the most conservative design rather than sharing in the risk and decision making opportunities and any subsequent economies.

While there are places for the PSD approach, it is not an ideal approach for every project and should not be used as a broad brush for public infrastructure projects. The PSD approach would be appropriate where reliable methods for measuring or observing performance of a structure are not available, for example on remote sites with intermittent site visits or projects with missing or unreliable monitoring data from which to make observations and design adjustment decisions.

CASE STUDY – LAUNCH SHAFT 1 (LS1)

The West Launch Area- Launch Shaft 1 (LS1), just east of Black Creek Drive along Eglinton Avenue West in Toronto, Ontario, is supported by a combination of internal bracing and tied-back anchor shoring systems. LS1 was awarded in advance of the main Eglinton Crosstown Light Rail Transit Project's tunnelling contract to expedite the overall construction schedule.

The site occupies the south half of Eglinton Avenue West bordered by the diverted road to the North, Keelesdale Park to the South and Black Creek to the West (Figure 2). The L-shaped excavation typically ranges from 12 to 15m deep and measures 44 m by 61 m. The shoring system constructed at LS1 was the result of contractor driven design changes to the original PSD driven shoring, transpiring after pile installation had begun in early 2012. Figure 3 and Figure 4 show contrasting schematics of the original prescriptive shoring design, and contractor-driven shoring alternative redesign, respectively.

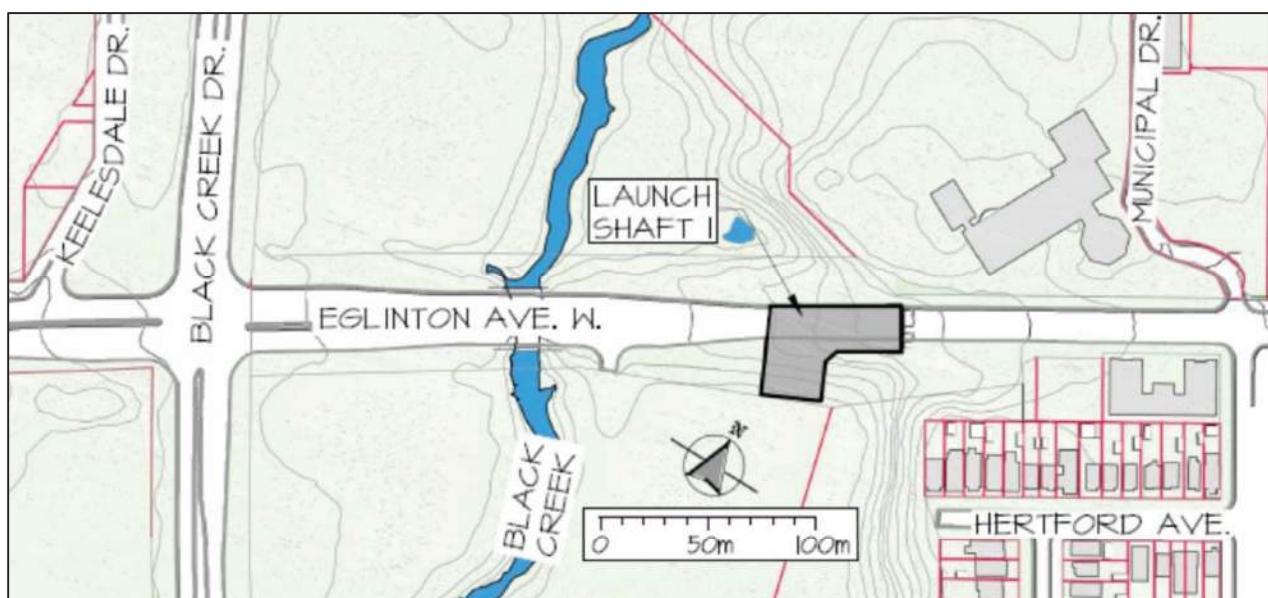


Fig.2. Launch Shaft 1 – Site Location Plan

Prior to construction, the Shoring Contractor considered retaining Isherwood to provide a Value Engineering design with hopes of realizing improved constructability and construction schedule while maintaining adequate shoring performance. Due to schedule and review process concerns the Shoring Contractor abandoned this approach. After pile installation was underway, the redesign initiative was restarted by the General Contractor and Shoring Contractor after the Owner realized the original scheme made it impossible to hand over the shaft to the next contract for tunnelling operations on schedule. The contractor-designer collaboration led to a shoring redesign by leveraging the Observational Method, the Contractors' strengths and resources, and local knowledge of Toronto's soils to realize significant improvements.

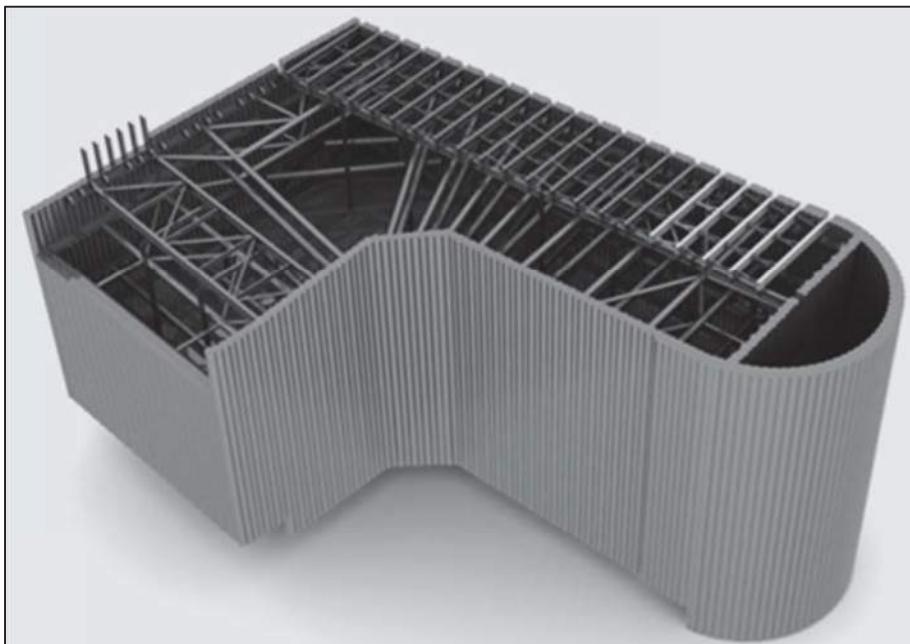


Fig. 3. Original PSD Design – Schematic (117 rock anchors not shown for clarity)

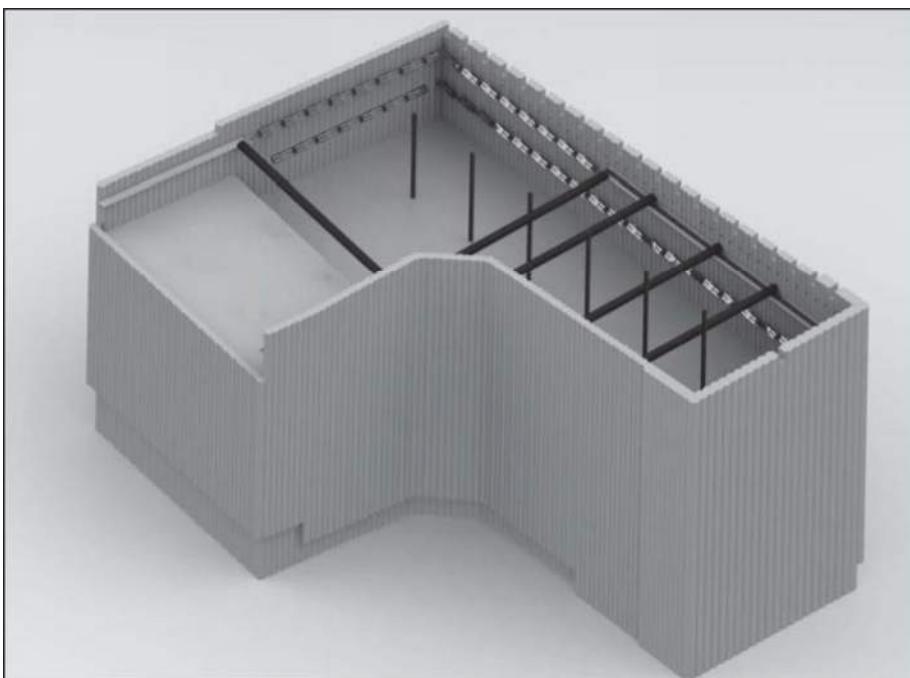


Fig. 4. Final Redesign – Schematic (16 contingency deflection control anchors not shown)

The redesigned shoring scheme was developed based on local excavation shoring design methods. Requests to the owner for deviation from the original PSD and the constraints which influenced its development, proved challenging. The owner's team was unmotivated to introduce "uncertainty" (or risk) into the original shoring design, already in hand: the result of an owner driven prescriptive specification intended to mitigate risk and generate "certainty" about the end product.

Original Shoring Design Inputs:

- (a) Contract Geotechnical Design Parameters
- (b) Uncertainty regarding the variability of the glaciated soil stratigraphy. Example of description provided for two of soil layers:

Material:	Silty clay to clayey silt	Silty sand to sandy silt
Elevation (m):	116.6 - 89	100.5-88.7
Relative Density (Typical):	Very soft to hard (stiff)	Loose to very dense (dense)
- (c) Contract Loading Envelopes
- (d) Contract Geometry Requirements:
 - a. "Design vertical distance between horizontal restraints not to exceed 4 m."
 - b. "Do not exceed 1 m for vertical distance from centre of line of lowest horizontal restraint to bottom of excavation."

The initial redesign initiative was focused on the headwall area where the original design included a caisson wall backed by an interlocking arched secant wall with jet grouting inside and outside the arch to create a solid block for the next contract tunnelling operations. The redesign of the headwall eliminated both the arch and jet grouting. Fibreglass reinforced cages in larger diameter holes were used to achieve the required design capacity. The design of the straight fibreglass wall significantly improved the schedule by allowing the elimination of forty 1.2 m (4 ft.) diameter drilled holes, but also eliminated the environmental risk of containing the jet grout spoils near Black Creek, various parks and conservation lands. The elimination of the arch and associated jet grouting also reduced the working area needed along Eglinton by 14 m (45 feet), improving the flow of traffic along Eglinton Ave. and reducing the impact to the public and local community. The redesign of the headwall saved over 3% of the total cost of construction.

The redesign significantly improved constructability and construction access in the shaft by using a combination of rock anchors, deflection control soil anchors, and internal bracing. The use of additional rock anchors allowed for improved construction access during excavation and subsequent tunnelling activities through elimination of struts and creation of a large strut free hoisting area to service both TBM operations. The initial project geotechnical report did not recommend use of soil anchors due to concerns with creep susceptible soils and shaft design life. Instead, design parameters for rock anchors were provided and installation challenges were discussed. In order to determine suitability of soil anchors instead of rock anchors, a sacrificial soil anchor test program was carried out in June 2012. Following review of the test results and findings, concerns still lingered within the Owner's consulting team and there was no desire within the Owner's team to share the risk of this change from the contract geotechnical recommendations. Despite proof of suitability per PTI testing and acceptance guidelines, the motivation for soil anchor use in the redesign disappeared, as the Contracting team would have to assume all performance risk. Instead, rock anchors were used as primary support members and secondary temporary soil anchors were added as a design contingency for deflection control for use until the base slab was installed.

In order to achieve agreement to proceed with the redesign from the owner, a clause in the contract design documents regarding use of a more complex soil-structure analysis in lieu of the specified pressure diagrams and constraints was utilized. A Finite Element Analysis using Plaxis 2D was submitted to the owner in November 2012 to confirm shoring redesign assumptions and establish a baseline for anticipated shoring performance. Permission was granted by the owner to proceed with the redesigned hybrid shoring

scheme in December 2012. Figure 5 shows the redesigned scheme for a section cut through the North and South Walls as illustrated in Figure 7. Struts were used as first row supports, rock anchors were used as second row bracing and deflection soil anchors were designed as a contingency to control potential shoring and toe movement to ensure shaft performance. Figure 6 shows FEA predicted final excavation total displacements for the section shown in Figure 5.

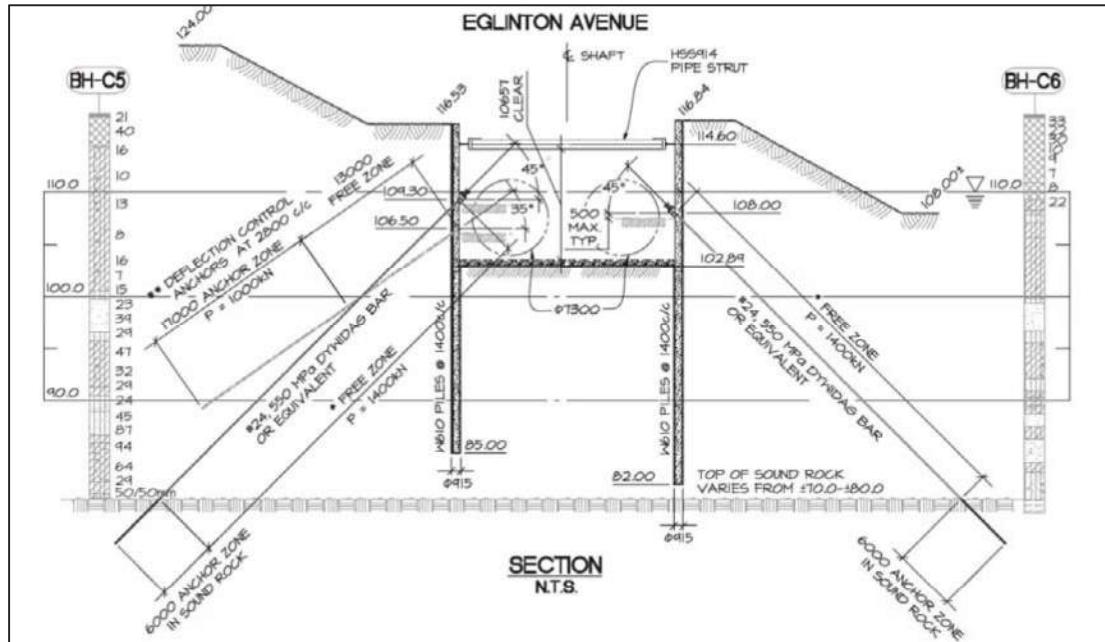


Fig. 5. Redesigned Shoring Section

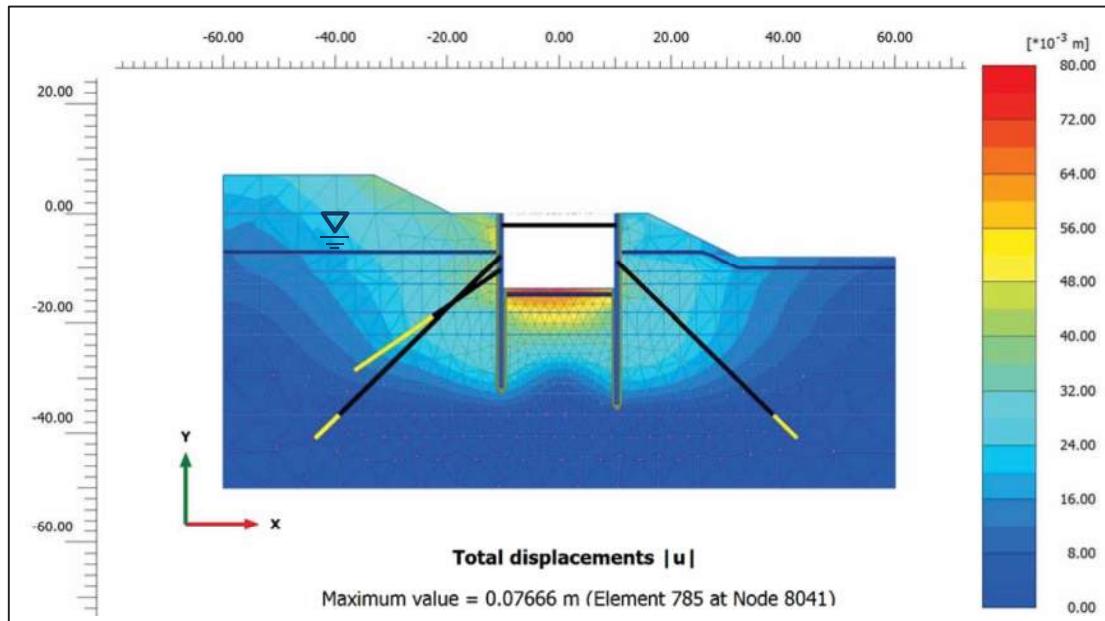


Fig. 6. FEA predicted final excavation total displacements

Shaft monitoring played a crucial role in the redesign and implementation of the observational method at LS1. Unfortunately, due to the original PSD approach, amending the monitoring plan to the new design proved contractually challenging. During construction, results of the monitoring program (inclinometers) were compared to the results predicted in the FEA Report to ensure the shoring system performed as anticipated and per agreed specification baselines.

Figure 7 highlights pile inclinometer locations. The inclinometer results for Pile SP110 on the North Wall and Pile SP84 on the West Wall are shown below in Figure 8 and 9 for various stages of the excavation.

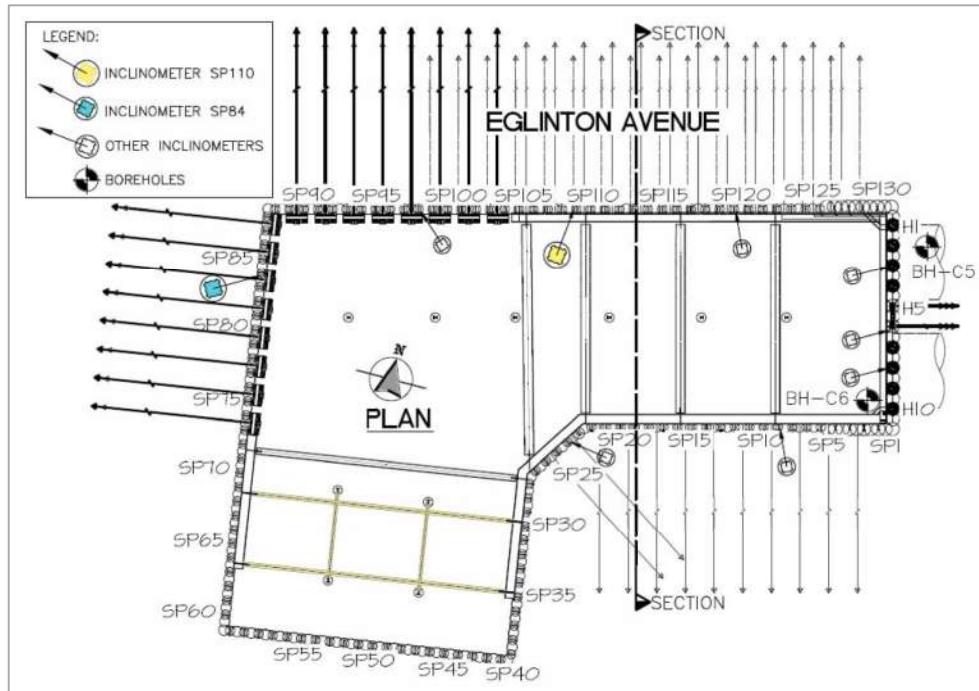
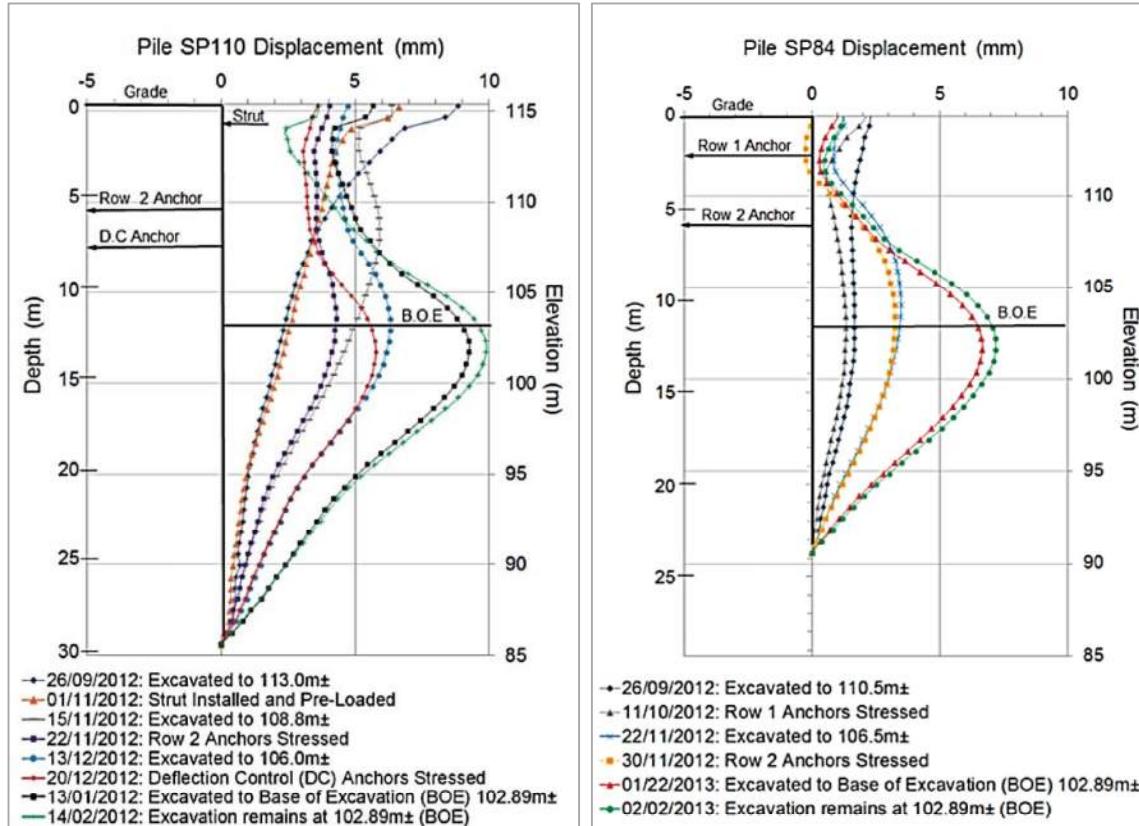


Fig.7. Inclinometer Monitoring Plan



The redesign saved at least 3 months on the shaft construction schedule, allowing it to be constructed in time for LS1 to successfully receive two tunnel boring machines, an impossibility with the original PSD. In addition, the redesign saved a significant amount of schedule for the following contract by providing a more efficient layout for removal and material handling for tunnelling of the next 3.5 km of the LRT line, and would have resulted in more cost competitive tenders. In addition to the schedule benefits to the Owner, the LS1 shoring redesign helped the Shoring Contractor save money as opposed to projecting a loss if the original PSD design had been built. A comparison of bill of materials for the internal bracing is presented in Table 1

Table 1: Comparison of Bill of Materials for PSD Design versus Redesign

	Original PSD Design	Final Redesign
Walers – Weight	160900 kg (354800 lbs)	75200 kg (165900 lbs)
Internal Bracing – Weight	293500 kg (647000 lbs)	88300 kg (194700 lbs)
Rock Anchors – Quantity	117	63
Deflection Control Soil Anchors – Quantity	N/A	16

Figure 10 shows a photo taken spring 2013 from the West Wall of LS1, looking towards the East Headwall during segmental assembly of TBM Dennis. The modest shoring movements of 10 mm were far less than the 35 mm review level and 50 mm alert level limits set in the contract. Thus, had a strictly performance based design been used from the inception of the project, with a harmonized shoring monitoring plan, there would have been a further opportunity for schedule and cost savings. A more efficient system could have been designed with use of shorter, lighter shoring piles and eliminating use of deflection control anchors, resulting in further improvements to schedule, constructability, carbon impact, and additional estimated project savings of \$2M with no significant performance impact.

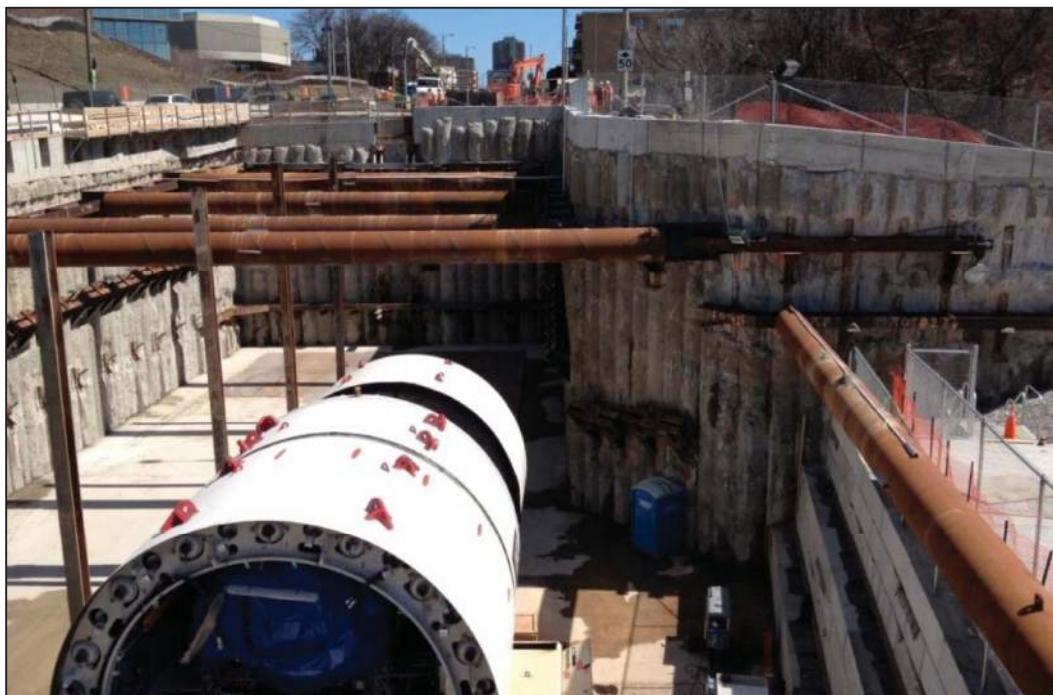


Fig. 10. Photo of LS1 taken Spring 2012, view looking East from the top of the West Wall

THE ALTERNATIVE APPROACH

Based on Isherwood's 45 years of experience with a variety of similar projects in the Toronto Area, the suggested alternative approach to the PSD method of tendering projects is to build opportunity for the use of the Observational Method into project contracts and specifications. The use of the Observational Method, as developed by Terzaghi and formalized by Peck (1969), allows for the design to be developed for maximum efficiency while guaranteeing safety and results in a performance based design specification rather than a prescriptive one. It is effective as a method of risk management to respond to geotechnical uncertainties with respect to soil parameters, soil structure analysis, and construction methodologies by using active feedback regarding the structure performance. This feedback is then used to confirm or modify the base design throughout construction (Powderham 2004).

Various researchers and authors (Peck 1969 and 2001, Le Masurier et al. 2006, Powderham 2004) discuss the Observational Method at length and show its proper use minimizes risk when dealing with uncertainty in the ground. Furthermore, the application of the method leads to increases in safety (Terzaghi et al. 1996) because as knowledge of the actual response to construction increases, uncertainties and risks reduce. If used from the beginning of a project the Observational Method may enable the best possible design with respect to safety, economy, and schedule by allowing time for the development of innovative and creative concepts to project constraints (Peck 1969). This approach also encourages engaging contractors and engineers who have local knowledge of the "dirt" required for effective use of the Observational Method.

While the concept of using the Observational Method is over half a century old, the authors are unaware of an effective method for its inclusion in major public subsurface infrastructure contracts that allows for its effective use, while sharing design change risk equitably between parties within a project. This is a significant hurdle on larger transit projects, where there are many parties reviewing and/or approving design methodology and there is no effective system set up to handle such changes with the speed required to make this approach reliable and effective. Without the risk sharing and management systems issues addressed properly within a contract and project organization, Contractors and Owners will not see the full benefit of its use, and the project team will be encouraged to try to shed risk rather than sharing opportunities resulting in inflated costs and construction schedules. This aversion to sharing risk will diminish the effectiveness of the method, and its ability to decrease costs, durations, and the environmental impact of a project.

Setting the framework for a successful project leveraging the Observational Method requires time for effective planning and innovation surrounding the design. This approach allows for a design based on the most probable conditions founded on experience, and modifications to the design based on performance. In these projects, a Geotechnical Baseline Report (GBR) is a solid foundation for contractually outlining the range of expected conditions for design of contingency plans. These designs would address for the range of conditions outside of those considered most probable, and conditions found outside those outlined in the GBR would still constitute changed conditions contractually. Further, the allowance for the contingencies would have to be built into projects in the beginning, so they are set up with adequate budgets and avoid potential cost overruns. Since this would be outlined during bidding of a project, Owners would have the time to evaluate the proposed alternatives and contingency plans in a competitive environment and choose the approach best suited to the project, geotechnical conditions, and risk assessment. Finally, after the established baseline is agreed by both the Owner and Contractor(s), the allowance for use of the contingency plans will have to be addressed in typical contract language, such as those surrounding liquidated damages.

THE SUGGESTED PROCEDURE – BASE COST PLUS CONTINGENCY

Based on Isherwood's experience with PSD and transit projects in the Toronto area like LS1, restructuring how these projects are tendered and bid will provide more opportunity to leverage local experience, promote design innovation, and encourage efficient designs reducing the financial, environmental, and societal costs to Owners and the public. This paper attempts to outline a suggested procedure to initiate a discussion on inclusion of performance based design using the Observational Method in similar projects:

- (a) Owner's team to define project scope and develop a GBR including established geotechnical design parameter variability
- (b) Bidding Contractors to establish:
 - a. Base bid design founded on experience and judgement of most probable conditions
 - b. Contingency design plans for GBR outlined geotechnical design parameter variability
- (c) Bidding Contractors to submit tender price as "Base Cost plus Contingency"
 - a. Summary of base bid design plus contingency plans with budgeted costs for contingency plan execution and associated schedule impacts.
- (d) Project Agreement/Contract to include procedure for timely use of contingency designs and define the effect on the base contract
 - a. Unit rates for contingency work, adjustment to liquidated damages clauses for additional contingency plan execution schedule, etc.
- (e) Post contract award - Successful Contractor's team to outline method of observation to monitor design performance during construction. Applicable review and alert levels for engagement of contingency designs are to be agreed by project team prior to start of construction.

CONCLUSION

Contracts using a prescriptive specification design (PSD) approach can lead to unnecessarily conservative designs and less control over construction activity and structure performance. In addition, the PSD approach can foster an environment for development of an "it's overdesigned" mentality and this presents a risk to the industry as a whole. A performance-based approach to project contracts and specifications using the Observational Method can lead to more efficient projects with shorter construction durations, increased safety, and decreased project costs. This method relies on monitoring and therefore more emphasis on accurate, timely monitoring results within contract specifications. This approach allows for leveraging local experience from both Contractors and Consultants to the project benefit. Our hope is those entrusted with the responsibility of stewarding public money recognize there is a viable and valuable alternative approach.

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