Contract Practices for Geotechnical Instrumentation

Part 1 - Introduction

John Dunnicliff

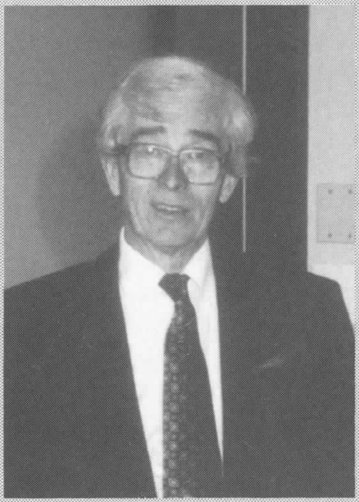
Background

When Lynn Pugh, Managing Editor of Geotechnical News, asked me last year if I would act as editor for an issue on instrumentation, I first thought of a series of good case histories, with a focus on lessons learned about performance of instrumentation. That would have been very readable, very practical, very constructive, particularly if authors had admitted some mistakes from which we could all learn. Of course we all like to learn from the mistakes of others! But then I decided to face up to one of the make-or-break issues with geotechnical instrumentation: the issue of contract practices. This isn't the most swinging subject, but because its importance often overrides so many other aspects of planning and executing a geotechnical instrumentation program, I decided to concentrate on this topic. For those of you who would choke on what you may consider a non-spicy diet, I've included some GIN and have solicited two other articles (see later), to spice up this issue of the magazine.

I'll start with a few stage-setting items.

John Dunnicliff

John Dunnicliff received masters degrees from Oxford and Harvard Universities, with concentration in geotechnical engineering.
His primary activity is consulting engineering, specializing in geotechnical instrumentation. His office is in Natick, Massachusetts. John has been associated with instrumentation of numerous projects including most those described in these articles.
John has also been a frequent continuing education instructor for various professional organizations, government agencies, universities and consulting firms. He is the author of the 1988 book "Geotechnical Instrumentation for Monitoring Field Performance", and in 1984 he worked



with Ralph Peck and Don Deere to develop the book "Judgment in Geotechnical Engineering: The Professional Legacy of Ralph B. Peck".

Where Do Contract Practices Fit into the Big Picture?

Decisions on contract practices are usually part of the systematic planning process that we face when embarking on a geotechnical instrumentation program. Table 1 summarizes the steps in this process, together with steps in execution. If you want to read more about these steps, there's much more in the red book[1]. You'll see that Steps 9, 17 and 21 are the steps that require decisions on contract practices, followed by specification writing.

For readers who have already seen this table too many times in my other publications, please note the addition of Step 15 "Prepare Instrumentation System Design Report." This has been added at the suggestion of Gordon Green, who wrote to me:

On reviewing Table 1 I believe an important topic is missing - I've had this thought for a few years now. Somewhere in the sequence, after item 14 I think, there needs to be "Prepare Instrumentation System Design Report". This should include most of items 1-14 and forces the designer to produce a definitive document that covers all these issues. Specifications are a separate and follow-up item. Unfortunately too many clients/designers think

(1) The colloquial name for ":Geotechnical Instrumentation for Monitoring Field Performance," 1988, Wiley, 577 pp.

that the "specs" = "the design". They are very definitely not. If you believe that steps 1-14 etc. are necessary then I also think this new step is necessary. It forces the user to write down everything, at which point it can be reviewed and checked that everything is consistent, and that the plan is a good one and covers the needs of the project. Reviewing the "specs" for this is too late.

I agree with Gordon. At his suggestion I have also added Step 9.

Table 1. Steps to Follow in Developing a Successful Monitoring Program Using Geotechnical Instrumentation.

Planning Phase

1. Define the Project Conditions
2. Predict Mechanisms that Control Behavior
3. Define the Geotechnical Questions that Need to Be Answered
4. Define the Purpose of the Instrumentation
5. Select the Parameters to Be Monitored
6. Predict Magnitudes of Change
7. Devise Remedial Action
8. Assign Tasks for Design, Construction, and Operation Phases
9. Select Contract Method
10. Select Instruments
11. Select Instrument Locations
12. Plan Recording of Factors that May Influence Measured Data
13. Establish Procedures for Ensuring Reading Correctness
14. List the Specific Purpose of Each Instrument
15. Prepare Instrumentation System Design Report
16. Prepare Budget
17. Write Specifications for Procurement of Instrumentation Materials
18. Plan Installation
19. Plan Regular Calibration and Maintenance
20. Plan Data Collection, Processing, Presentation, Interpretation, Reporting, and Implementation
21. Write Specifications for Field Instrumentation Services
22. Update Budget

Execution Phase

23. Procure Instruments
24. Install Instruments
25. Calibrate and Maintain Instruments
26. Collect Data
27. Process and Present Data
28. Interpret Data
29. Report Conclusions
30. Implement

Goals of Specification Writing

Two recent articles in Civil Engineering magazine provide wise guidance on goals and rules for good specification writing. The opening paragraph of the first[2] says:

A clearly worded set of specifications is vital to the success of a construction project. Poorly written specifications are the source of confusion, mistakes and, often, lawsuits. Therefore, it is essential for the writer to work carefully; following a few simple rules will help produce clear, well-understood specifications.

The opening paragraph of the second[3] says

Specification writing is typically delegated to junior staff at the end of the project on the premise that it is an easy assignment that simply involves copying from the last job. This is a mistake. On most projects the specifications have precedence over the drawings, to which engineers devote most of their time. The result is that the mistakes of an inexperienced engineer at the end of a design cycle can outrank the good work of a more senior designer.

The goals are: **clear**, **consistent**, **complete**, **correct**, and also **equitable**. And this takes **care** and **diligence**. Not easy goals for geotechnical engineers, who are usually not trained in specification writing - but we can learn.

(2) Goldbloom, Joseph, (1992), "Improving Specifications," Civil Engineering, September, pp. 68-70.
(3) Arora, Madan L., (1994), "Writing Effective Specifications," Civil Engineering, March, pp. 69-71.

Types of Specifications

There are two basic types of specifications: descriptive and performance. In descriptive specifications, means and methods are defined, whereas in performance specifications only the end result is specified.

In civil engineering construction most aspects of the finished product can be observed, evaluated or tested during construction, so that with either type of specification the construction manager can ensure that the end product is what the designer intended. However, with geotechnical instrumentation, we can rarely **see** what we've constructed, and we can rarely **test** it to be certain that it works after installation. For example, a piezometer in a borehole may appear to work correctly after installation, but how do we know that it is correctly and completely sealed in the stratum of interest? We may not discover an incomplete seal until we get strange data later, when it's too late to do much about it. Because we often cannot see or test, we must be very critical about means and methods. Said another way, because we can't verify quality by seeing and testing, we control quality by agreeing on detailed step-by-step procedures which, if followed, give our best shot at ensuring quality. It's for this reason that, before the start of construction, we should get into much more detail when preparing to install instrumentation than we do for many other construction tasks.

Goals of this Series of Articles

In Chapters 5 and 6 of the red book, I tried, with the help of Bob Vansant, a civil engineer and lawyer, to provide guidance on contract practices for procurement of instrumentation materials and for field instrumentation services (installation, data collection, data management and other tasks). But that was written seven years ago, and I hope I've learned something during those seven years. The goal of this series of articles is to look at what the North American geotechnical community has experienced in recent years, both those who have written specifications and those who have had to live with specifications written by others. As I began this effort, I hoped that by doing this I could point towards some better directions for the future.

As the effort has progressed, I realize that I have to admit a significant shortcoming to these articles: they are almost exclusively about "mega-projects." That is so because that is how most of my time has been spent. To what extent these articles are also relevant to smaller projects, I'll have to let others decide. I believe they are. Future issues of this magazine would be good places to share your opinions with others.

Definition of Terms

The following terms are used in this series of articles:

Materials. The instruments themselves. The hardware.

Field Instrumentation Services. Installation of instruments, maintenance, regular calibration, data collection, data management.

Request for Quotation (RFQ). A request, addressed to instrument suppliers, for materials prices. The RFQ may call for information on suppliers' experience, previous users, delivery time, component details. Selection will be based on a combination of price and other factors.

Request for Proposal (RFP). A request, usually addressed to geotechnical engineering firms, for field instrumentation services. The RFP may call only for qualifications, experience, approach to the work, and names of individuals who would be assigned to the project. After receipt of proposals, a short list is usually prepared, interviews conducted, and a rating made. Financial negotiations are conducted with the first-rated firm which, if successful, lead to a selection and a contract. If not successful, negotiations are conducted with the second-rated firm, and so on.

Bid Specification. A specification that requires an instrument supplier or a construction contractor to bid a price in price competition with others. A geotechnical engineering firm may act as a construction contractor or as a subcontractor to a construction contractor.

Professional Service Specification. A specification that forms part of an RFP, to define the work included.

Assigned Supplier. When materials are procured through the construction contractor, the *assigned supplier* approach can be used to allow the owner or design consultant to retain control over selection of materials. A line item in the bid schedule is designated as an *allowance item* with a description *"Furnish instruments."* The engineer's estimate is included in the amount column (or in the unit price column with a bid markup), and the cost is included in the total bid price. Payment is based on actual materials supplied. The specification states that, after contract award, the owner's representative will determine instrument descriptions, sources, quantities and prices, and will provide this information to the construction contractor. The construction contractor is then required to place orders, within a specified time period, and the instrument suppliers become assigned suppliers. The construction contractor's monthly payment requests to the owner are supported by including copies of invoices from suppliers. The owner's estimate should not be regarded as a *not to exceed* figure, and the contract price should be increased by change order if needed.

Assigned Subcontractor. When

field instrumentation services are obtained through the construction contractor, the assigned subcontractor approach can be used to allow the owner or design consultant to retain control over selection of personnel. The procedure is essentially the same as the assigned supplier procedure, except that the line item description is *"Provide Services of Specialist Field Instrumentation Personnel,"* and payment is based on actual time expended. The specification states that, after contract award, the construction contractor will be instructed to enter into a subcontract with an organization selected by the owner and agreeable to the construction contractor, and the organization becomes an *assigned subcontractor.*

Review of Recommendations in Red Book Chapter 5 for Procurement of Instrumentation Materials

Table 2. Who Should Buy the Materials? Advantages and Limitations. 1988 Recommendations

Procurement by	Advantages	Limitations
Construction contractor	Contractor's liability is clear.	If an *acceptable equivalent* provision is required, specification covering all salient points is needed to guard against supply of an undesirable substitution. Contractor will generally buy lowest-cost instruments, with risk of low quality and invalid measurement data.
Owner	Minimum cost (because no markup). Owner has direct control over substitutions. Can select between competitive bid method or (if permitted by owner's regulations) negotiation with one or more suppliers.	Contractor has no liability for nonperformance. Owner may purchase lowest price instruments rather than highest quality. Cost is in owner's budget.
Design consultant	Same as for owner, except that cost will be marked up.	Contractor (or other party responsible for field instrumentation services) has no liability for nonperformance. Cost is included in design fee.
Construction contractor, with assigned suppliers	Same as for design consultant.	Contractor has no liability for nonperformance.

Three recommendations were given in 1988.

First, a recommendation as to who should buy materials. Table 2 summarizes the options. It was recommended that procurement should preferably be under the direct control of the owner or design consultant; thus, the "construction contractor" option is the least desirable. Selection among the other three options depends on factors specific to each project. Despite this recommendation, it was acknowledged that many owners and construction managers require procurement by the construction contractor, and therefore several pages of guidelines were given for content of bid specifications.

Second, descriptive and performance specifications were compared, with a conclusion that descriptive specifications are more common, and are generally preferable. A discussion was included on whether *"brand names and model numbers"* are desirable in specifications, and on the need for *"or acceptable equivalent"* provisions; that discussion will not be repeated here.

Third, methods for determining price were compared: bid and negotiation. Precedents were given for selecting a negotiation method *in order to avoid receiving a product that merely meets the minimum requirements of a solicitation instead of the one that is best for the job.* A plea was made: *Lowest cost of an instrument should never be allowed to dominate the selection, and the least expensive instrument is not likely to re-*

sult in minimum total cost. In evaluating the economics of alternative instruments, the overall cost of procuring, calibration, installation, maintenance, monitoring, replacement of bad instruments and data processing should be compared.

Review of Recommendations in Red Book Chapter 6 for Field Instrumentation Services

Three recommendations were given in 1988.

First, a recommendation as to who should install instruments. Table 3 defines the options (and the five "Method numbers": for more detail see Chapter 6 in the red book), and summarizes advantages and limitations. The term "specialist" in Table 3 refers to people who will perform instrument installation tasks that are outside the capabilities of the average prime construction contractor. It is not suggested that these specialists should perform tasks that are within those capabilities, such as excavation, backfilling, welding, protection. It was recommended that Method 2 should be used only for simple installations such as settlement platforms that can be considered as normal construction items, and that Methods 1, 4, and 5 are more likely to result in valid measurement data than Method 3. Despite this recommendation, it was acknowledged that many owners and construction managers require installation by the construction contractor, and therefore several pages of guidelines were given for content of bid specifications.

Second, similar recommendations were made for maintenance, regular calibration, data collection and processing.

Third, data interpretation must be the direct responsibility of the owner or owner's representative, hence favoring Methods 1, 4 and 5. If Method 3 is used, the data must be handed to the owner for interpretation, requiring that the owner has an experienced representative involved with all phases of the program.

Summary of Experience Since 1988

Since publication of the red book, I've been involved with writing geotechnical instrumentation specifications for the projects included in this series of articles, with the exception of Mount Baker Ridge Tunnel and Megabuck Tunnel. In all cases I tried to convince decision-makers to avoid using bid specifications, and to avoid a lump sum compensation method, but often without success. The primary arguments used by decision-makers were:

The bid method will give us the lowest price.
To do it any other way will take responsibility and liability from the construction contractor.
We've always done it this way, therefore...
We're required to do it this way.
We want the cost to be covered by federal funding.
It is the sort of work that a technician can easily do.

The counter-arguments:

*But what we need is **QUALITY**, and we often don't get that when bid specifications are used.*
Placing excessive or unreasonable risk on the prime contractor's shoulders will inflate bid prices.
We can take care of the responsibility/liability concern with appropriate specification wording.
The federal funding issue can be taken care of by using the assigned supplier and assigned subcontractor method.
Yes, some of this work can be done by technicians, but a significant part can't. An obvious example: data interpretation.
The prime contractor usually isn't interested in the instruments, and considers them a nuisance.
Lump sum payment methods are too inflexible.

were usually not heard.

Since 1988, I have seen only descriptive specifications (no performance specifications) for geotechnical instrumentation. Methods adopted by decision-makers at the projects included in this series of articles are summarized in Tables 4 and 5. I had hoped to include more projects, but some others with which I've been involved are amid contentious issues that prevent publication at this time.

Several observations can be made from the contents of Tables 4 and 5.

For these projects, instrumentation materials have usually been procured by the construction contractor or the design consultant. The owner has not procured materials directly (but this method is used by some public agencies, notably some Corps of Engineers Districts). The assigned supplier method has been used in one case only.

For these projects, field instrumentation services have been provided in a wide variety of ways, but none of these projects have used Method 2 or the full version of Method 5.

Table 3. Advantages and Limitations of Various Contractual Arrangements for Instrumentation Installation. 1988 Recommendations.

Method	Advantages	Limitations
1. Specialist work by owner's personnel.	Owner has direct control over cost and quality.	Potential problems with contractor cooperation if instrumentation work interferes with other work. Owner must plan for workload well in advance. Assumes owner has necessary inhouse skills. Cannot always be financed by construction funds.
2. Bid items in construction contract, without personnel experience criteria.	Installation costs will usually be low. Financed by construction funds.	Generally, contractor will shop for lowest price subcontractor, with risk of lowest quality and invalid measurement data. Requires strong and experienced supervision by owner's representative.
3. Bid items in construction contract, with personnel experience criteria.	Installation costs will usually be low. Excludes inexperienced instrumentation subcontractors. Financed by construction funds.	Generally, contractor will shop for lowest price "qualified" subcontractor, with risk of subcontractor having inadequate price, cutting corners, and thus invalid measurement data. Often difficult to substantiate desire to reject questionably qualified subcontractor. Usually requires strong and experienced supervision by owner's representative.
4. Instrumentation specialist selected by and contracting with owner.	Owner has direct control over cost and quality. Instrumentation specialist can, if retained early enough, assist with design of monitoring program. Instrumentation specialist may have other skills, such as data interpretation, that will be useful to the owner.	Potential problems with contractor cooperation if instrumentation work interferes with other work. Cannot always be financed by construction funds. Requires some effort by owner to select specialist.
5. Instrumentation specialist selected by owner and contractor, and contracting with contractor as an assigned subcontractor.	Owner has direct control over cost and, via the owner's representative, quality. Facilitates cooperation and scheduling with contractor. Financed by construction funds.	Selection is made after award of construction contract: instrumentation specialist therefore cannot assist with design of monitoring program. Assumes "professionalism" on part of instrumentation specialist, who has negotiated with the owner but contracted with the construction contractor. Requires some effort by owner to select specialist. Not permitted under some public agency regulations.

Table 4. Methods Adopted for Procurement of Instrumentation Materials

Procurement by	Project
Construction contractor	Boston Central Artery/Third Harbor Tunnel (CA/T) Mn/ROAD Supercollider (SSC) (part) Megabuck Tunnel
Owner	None
Design consultant	SSC (part) Toronto Rapid Transit Expansion Program (RTEP)
Construction contractor, with assigned suppliers	Mt. Baker Ridge Tunnel

Table 5. Methods Adopted for Field Instrumentation Services

Method	Project		
	Installation, Maintenance, Regular Calibration	Data Collection and Processing	Data Interpretation
1. Specialist work by owner's personnel.	None	Mn/ROAD Mt. Baker Ridge Tunnel (collection)	Mn/ROAD
2. Bid items in construction contract, without personnel experience criteria.	None	None	None
3. Bid items in construction contract, with personnel experience criteria.	CA/T Megabuck Tunnel Mn/ROAD Mt. Baker Ridge Tunnel (part) SSC (part) Toronto RTEP (part)	CA/T Megabuck Tunnel SSC (part) Toronto RTEP (part)	CA/T Megabuck Tunnel SSC (part) Toronto RTEP
4. Instrumentation specialist selected by and contracting with owner.	Mt. Baker Ridge Tunnel (part) SSC (part) Toronto RTEP (part)	CA/T SSC (part) Toronto RTEP (part) Mt. Baker Ridge Tunnel (processing)	CA/T SSC (part) Toronto RTEP Mt. Baker Ridge Tunnel
5. Instrumentation specialist selected by owner and contractor, and contracting with contractor as an assigned subcontractor.	None (but Mn/ROAD had list of pre-qualified subcontractors)	None	None

Contract Practices for Geotechnical Instrumentation Part 2 - Bid Specifications

Introduction

John Dunnicliff

This part of the series of articles includes projects listed in Tables 4 and 5 for which procurement of materials and field instrumentation services were the direct responsibility of the construction contractor, with bid specifications.

The sequence of projects is based on best readability, and not on importance or chronology.

Format of this Series of Articles

The following articles are grouped into two main parts: Part 2, Bid Specifications and Part 3, Professional Service Specifications. I asked each contributor to adopt the following format wherever possible:

- Description of Project
  - The big picture
  - Need for instrumentation
  - Roles of various parties
- Contract Method
  - Procurement of materials
  - Field instrumentation services for installation, data collection, interpretation
  - Contractor's liability/responsibility
  - Motivation and quality
  - Payment method
- Experience During Construction
  - Role of author's firm
  - Experience with contractor's liability/responsibility
  - Experience with contractor's motivation and quality
  - Experience with payment method
  - Other experience during construction
  - Lessons learned

Contributors are identified by name alongside each section. An alphabetical listing of contributors' names, titles and contact information is given after Part 4.

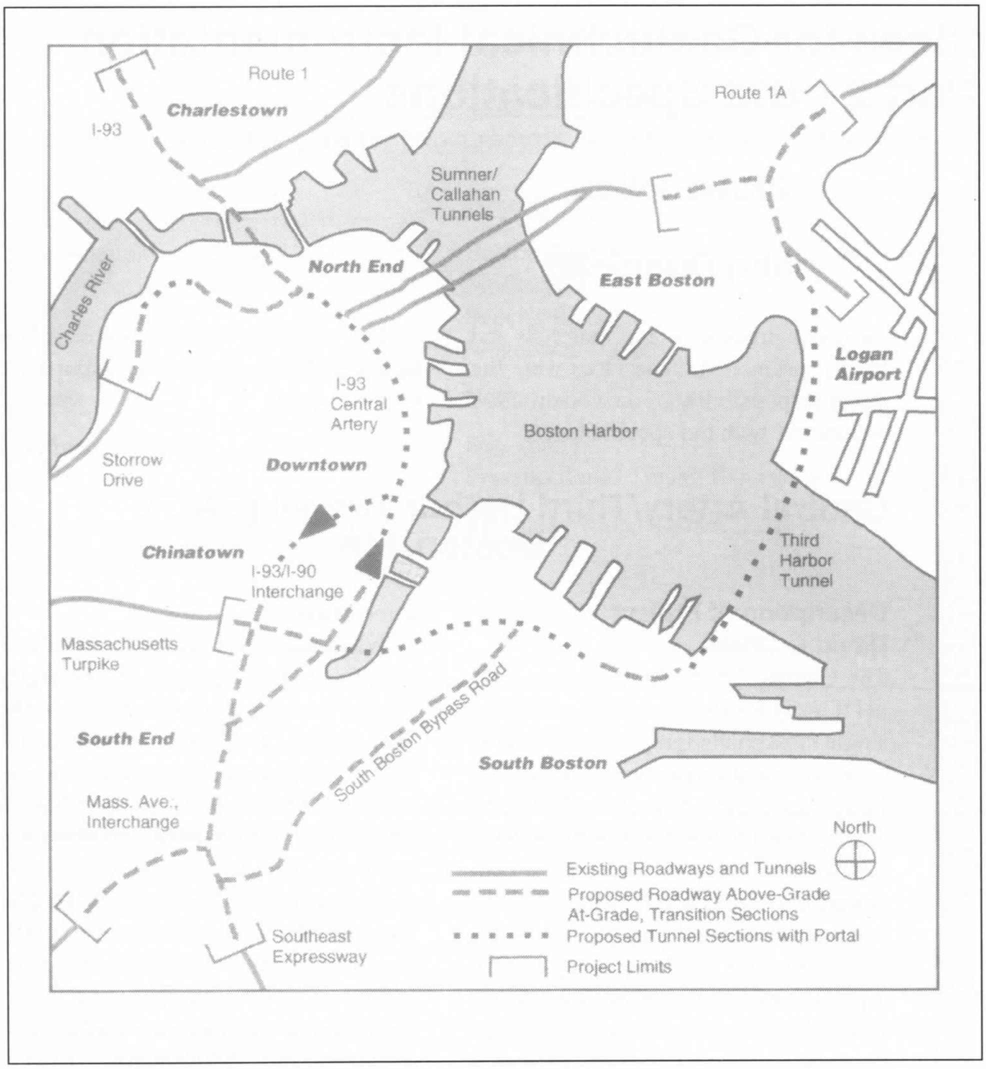
Central Artery/Third Harbor Tunnel (CA/T), Boston, MA

Description of Project
David L. Druss

The Central Artery/Third Harbor Tunnel (CA/T) Project represents one of the single most challenging endeavors from a geotechnical engineering standpoint. Few, if any, single projects in the United States have encompassed both the variety and magnitude of underground construction as the CA/T Project. The project is administered and funded by the Massachusetts Highway Department and the Federal Highway Administration. Significant features include: approximately four miles of cut-and-cover tunnel construction located within a heavily congested urban environment where dozens of buildings lie within the zone of influence of the construction; six locations where tunnels will be constructed either above, below or adjacent to active underground rail transit facilities, one of which involves the underpinning of a three-level subway station for the full width of the four-lane highway tunnel; an immersed tube tunnel, the excavation for which transitions from a 60 ft cut in massive bedrock to soft clay within a length of 300 ft; and viaduct piers with vertical and horizontal loads in the thousands of kips. The geotechnical instrumentation program represents the primary means of identifying construction activities and procedures which have the potential to result in detrimental impacts to surrounding facilities. Precise, accurate and timely reporting of data become essential to meeting the objectives of the instrumentation efforts.

What makes the geotechnical efforts even more challenging is the generally adverse ground conditions found in the Boston area. The high groundwater table, deep deposits of soft soils, and the presence of permeable strata combine to create an environment in which the potential for large deformations due to excavation activities becomes significant. The complexity of subsurface conditions results from a depositional environment which consisted of a combination of glaciation and marine sedimentation. Additionally, virtually the entire project alignment falls within reclaimed land for which a multitude of filling processes and materials were utilized. The generalized profile starting from the ground surface consists of fill, organic deposits, silty clay, dense glacial deposits, and bedrock. In some areas the soft silty clay extends to depths in excess of 150 ft. The bedrock properties are extremely variable, ranging from totally decomposed to very hard and massive.

Control of deformations and maintenance of prevailing groundwater levels represent the primary geotechnical objectives in CA/T Project construction, and thus defining the role of the geotechnical instrumentation program. Deformations associated with tunnel excavation have the potential to adversely impact scores of buildings, utilities, transit tunnels and other facilities which abut the alignment. Similarly, lowering of the groundwater table or



Central Artery/Third Harbor Tunnel Project, Boston, MA

decreases in piezometric pressures can also result in settlement of adjacent facilities. Marine clays and organic deposits encountered throughout the alignment are particularly sensitive to changes in groundwater conditions. Structures founded above, on or within these strata thus become subject to potential deformation. Additionally, should existing timber pile foundations become exposed to air for extended durations as a result of lowering of the groundwater table, deterioration may result.

As stated above, the CA/T alignment falls within close proximity to numerous facilities which are highly sensitive to deformations. There are numerous buildings which are designated as historic, therefore must be protected from experiencing architectural damage. There are also century-old transit tunnels for which structural and waterproofing integrity are to be maintained, and multistory office buildings for which excessive deformations could result in overstressing of structural members. For all these situations, tolerances for allowable deformations are very small, and thus deformations must be measured to a high degree of accuracy.

Construction vibrations represent another source of potential distress to adjacent structures and business activities. Buildings in poor structural condition may be prone to further distress due to construction vibrations. Additionally, facades or architectural masonry which are not adequately fastened to the structure could become detached. Moreover, vibration-sensitive equipment such as computer systems, electron microscopes, professional quality photo processing facilities, micro-circuit fabrication and testing machinery are housed in businesses throughout the alignment.

On a wider perspective, mitigation of impacts of CA/T Project construction activities to the urban environment represents a paramount commitment of the CA/T Project to the working and residential population of Boston. Implementation of an intensive construction mitigation program is included among the conditions, as stipulated in the Environmental Impact Statement, which allowed the CA/T Project to proceed. Containment of noise, traffic, air and water pollution, construction spoil and debris, as well as detrimental deformations of adjacent facilities are encompassed by the mitigation program. With respect to protection of adjacent facilities, the geotechnical instrumentation program is the key element of the mitigation effort.

Contract Method
David L. Druss and John Dunnicliff

Among the more lively topics of discussion in the early planning stages of the CA/T Project were those associated with assignment of responsibilities for geotechnical instrumentation. Two alternatives for primary responsibility for collection and reporting of instrumentation data were the subject of considerable debate - the construction contractors or a representative of the owner. Very logical arguments can be made to support the implementation of either approach.

The strongest factor which supports leaving the responsibility for data collection to the construction contractors is accountability. Since the contractor is responsible for construction, and in most cases on the CA/T Project, also for design of the temporary excavation support systems, the contractor should remain responsible for monitoring their performance as well. Such an approach is also consistent with the contractor's responsibility for maintaining the safety of the work. Another supportive argument is that there can be no excuses for receiving untimely or inaccurate data if the contractor retains primary responsibility for data collection.

The strongest case for assigning responsibility for data collection to a representative of the owner is a poor track record of performance where geotechnical instrumentation tasks were the responsibility of the construction contractor and included among the competitively bid items. Such has been the experience in numerous large public works projects. Additionally, in cases where the owner is responsible for construction management, the owner shares some degree of responsibility for the quality and performance of the work, and thus should not entirely disassociate itself from monitoring the excavation support systems or resultant impacts to adjacent facilities. Finally, if a monitoring program is conducted by the representative of the owner, and performed by a single entity on a project-wide basis, consistency among data collection procedures, monitoring frequencies, and formats of data presentation can be realized.

To best address the concerns raised by both camps, a "dual monitoring program" was implemented for the project. In the dual monitoring program both the construction contractors and the owner's representative, (the Management Consultant, Bechtel/Parsons Brinckerhoff: B/PB) collect and report instrumentation data. Primary responsibility for data collection is assigned to the construction contractors, and B/PB bears secondary responsibility. The construction contractors' responsibilities are described in this section, and B/PB's responsibilities are described in Part 3 (this part of the series of articles relates to bid specifications, whereas Part 3 relates to professional service specifications).

Construction contractors are responsible for procurement of materials, and for all field instrumentation services, including installation, maintenance, regular calibration, data collection, data management and interpretation. A single lump sum bid price is used for all the above tasks.

The project is divided into about 80 separate construction contracts, each with a Section Design Consultant

Table 6. Contents of CA/T Standard Special Provisions

Part	Article
1. Description	General Related work Definitions Purpose of geotechnical instrumentation program Responsibilities of Contractor Qualifications of Contractor's instrumentation personnel (field and office, drillers, surveyors) Quality assurance Submittals (personnel, materials, field procedures, data, plans of action relating to hazard warning levels) Scheduling work Storage of instruments
2. Materials	General (acceptable equivalents, instruction manuals) One article for each instrument type, including surveying instruments Factory calibration
3. Construction Methods	Pre-installation acceptance tests Installation - general (casing, grouting, Contractor's additional instruments, installation records) Installation of...(one article for each instrument type) Field calibration and maintenance Data collection (initial readings, other readings, schedule, records, Contractor's additional readings, access for Engineer) Data reduction, processing, plotting and reporting (data format, detailed plot requirements, report content and schedule, causal data) Damage to instrumentation Disclosure of data Interpretation and implementation of data (Contractor's responsibility, hazard warning levels, actions in event hazard warning levels are reached) Disposition of instruments
4. Compensation	Method of measurement Basis of payment Payment items

(SDC). The Management Consultant (Bechtel/Parsons Brinckerhoff) has prepared Standard Special Provisions (SSP) for geotechnical instrumentation, which are provided to each SDC. Table 6 lists the contents of the SSP. Each SDC tailors the SSP to the needs of the particular construction contract, and prepares plans and specifications accordingly. Recognizing the need for high quality instrumentation data, the SSP is both detailed and lengthy. Stringent personnel experience criteria are included. The specifications make it clear that the construction contractor bears the sole responsibility to collect data at specified frequencies, notify the Management Consultant if hazard warning levels are reached, and take appropriate corrective action when necessary.

Experience During Construction: Owner's Representative Siamac Vaghar

Role of Author's Firm

As described in Part 2, Bechtel/Parsons Brinckerhoff (B/PB) is retained by Massachusetts Highway Department as the Management Consultant for the CA/T Project. The role of B/PB includes:

- Providing a quality check on data collected by the construction contractors, and collecting supplemental data.
- Enforcing specifications for installation of instruments, data collection, reporting and interpretation by construction contractors.
- Providing an independent "first cut" evaluation of the instrumentation data with respect to the ongoing construction activities and the design assumptions.

B/PB also acts as the link to the Section Design Consultants, when more in-depth analyses involving design assumptions are needed.

Experience with Contractors' Liability/Responsibility

One of the goals of the dual monitoring program, requiring the contractors to collect and interpret instrumentation data, was to give the contractors "ownership" of responsibility for instrumentation. This goal has, to some extent, been achieved, as the contractors have had to stay involved with instrumentation issues. As the first recipient of their own data, the contractors have, on some occasions, been able to formulate corrective actions rapidly, thus eliminating the time that would have been lost during the transmission of data for evaluation by others. When independent corroborating data have been available, for example when our data and the contractor's data both showed the same magnitude of movement in an inclinometer casing, very rapid action was possible.

Typically instrumentation has been a low priority item for the prime contractors. They have tended to assign staff to the task, but not provide them with any real authority to resolve issues. Frequently, we have discussed and agreed to a certain action with the contractor's instrumentation subcontractor, only to find out later that it had remain unresolved, because the subcontractor either did not have the authority to promise action, or was overruled by the prime contractor's project manager. It is very common for instrumentation issues to be neglected in favor of "more pressing issues". There have been occasions when the prime contractor could not commit to the most minor of issues such as providing a backhoe for an hour to clear access to an instrument!

The specifications require the prime contractor and B/PB to meet once a week to resolve any outstanding issues. Except in a few contracts, these meetings became less productive because of the inability of the contractor or instrumentation subcontractor personnel in attendance to commit to actions or milestones.

The same "low priority status" has been responsible for numerous occasions when the contractors opted to proceed with excavations before formal initial readings had been taken on instruments in the vicinity, as required by the specifications.

Experience with Contractors' Motivation and Quality

The low priority given to instrumentation by some contractors has meant that there is a shortage of staff to cover the monitoring and evaluating of the instruments at the specified frequencies. Also, the quality of the data has sometimes been compromised in the interest of "just getting the report out of the door".

On a few contracts, the prime contractors have attempted to pick up a portion of the data collection effort, using their own personnel rather than the staff of a specialist subcontractor, presumably with some resulting cost savings to themselves. Since the subcontractors are still responsible for collating and quality checking of the data, this has resulted in delays, and difficulties in tracing the sources of questionable data.

Each prime contractor is of course interested in his own contract only. B/PB, as the overall Management Consultant, is interested in the project as a whole, and therefore in consistency between contracts. Often instruments from one contract have to be passed on to a new contract, or to an adjacent existing contract. It has been difficult at times to enforce the prime contractor to provide all that is required by the specifications, when it appears to be "unnecessary" for his work, or merely "niceties".

One such issue is the numbering of instruments. A prime contractor on a small contract can appear very convincing when he insists that his only two observation wells should be numbered 1 and 2, when B/PB insists on 32A-OW-50897 and 32A-OW-50898!

Experience with Payment Method

We have had considerable difficulty with the lump sum method of payment for instrumentation. Although there is typically a schedule of partial payments of the lump sum, the schedule is not always broken down to small enough components. It has been difficult, for example, to withhold payment for 12 inclinometers and 15 observation wells, if the contractor has not submitted as-built records for one of the wells!

Another persistent issue has been the problem of obtaining a credit, if instruments or readings are omitted, or reduced. Equally, additions or lengthening of instruments have always resulted in paper trails and time spent trying to evaluate the contractors' proposals for cost and effort.

Mn/ROAD, Wright County, MN

Christopher Groves

Description of Project

The Minnesota Department of Transportation (Mn/DOT) is conducting a long-term road research project consisting of three miles of instrumented pavement test sections to monitor the behavior of various road sections under long-term traffic and environmental conditions and pavement design variables. Pavement designs are asphalt and concrete with various base course configurations, with sections designed for an expected service life of five or ten years.

The project included a one-of-a-kind, detailed, instrumentation program to test the effects of stress, strain, frost, temperature, and ground moisture on pavements. There are 40 instrumented pavement sections; each section is monitored by its own cluster of instruments, with 24 different types and a total of more than 4,000 instruments being used. Mn/DOT is using a data acquisition system to monitor and collect data from the installed instruments on an ongoing basis.

As the first such program of this scale and scope to test the performance of highways, the information gathered will affect the future design of highways throughout cold regions, particularly in the northern United States, Canada, and Europe.

Contract Method

The State signed a single contract with the prime contractor to construct the pavements and install all the instrumentation. A list of pre-qualified instrumentation subcontractors was provided to bidders. Payment was in accordance with a schedule of unit prices, either for "furnish and install" or for "install." The prime contractor had the overall responsibility for the project, including the scheduling of work, all contractor-to-owner communications, and coordinating between subcontractors. The State signed a separate contract for the installation of all the data logging equipment and the software to run the data loggers. This separate contract left a gap in the accountability for the instruments and their calibration.

The instrumentation subcontractor was responsible for readings associated with post-installation acceptance tests, and the State subsequently was responsible for data collection, processing and interpretation.

Experience During Construction: Subcontractor

Role of Author's Firm

After a pre-qualification, administered by the Minnesota Department of Transportation, the competitive bidding process selected Shannon & Wilson, Inc., to be the instrumentation subcontractor (ISC) for the Mn/ROAD research project. Our responsibilities included developing installation procedures, providing installation details, fabricating several types of environmental instruments, connecting lead wires, testing, checking, and installing instruments, performing post-installation testing, and submitting the associated documentation. We were not involved in the development of the project objectives, selection of parameters to be measured, selection of instrument types, locations for instruments, or monitoring the instruments after the pavement was installed.

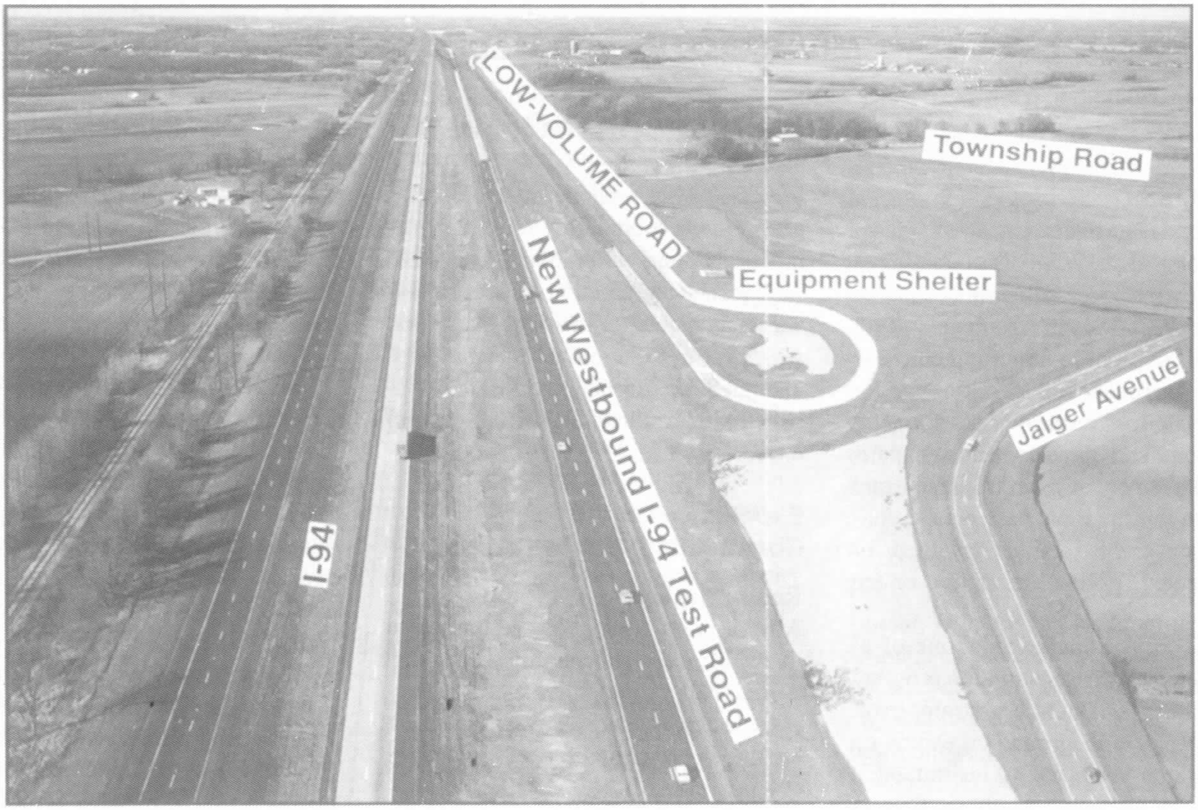
Experience with Contractor's Liability/Responsibility

We did not experience significant problems with liability, nor did we expect to. On a large government project such as this and where there is enough planning, budget, and technical resources, we do not expect there to be any major problems. We encountered little liability difficulty with the Mn/ROAD project, although we did have some difficulty with the definition of responsibilities. The specifications required that we develop installation details for the installation of instruments, but did not give us the full freedom to design as we would wish. Some State personnel believed that in this role we were the designer of record for the project. It is our position that the generation of drawings and details such as shop drawings did not, in fact, make us the designer of record.

While bidding the Mn/ROAD project, our greatest concern was over the lack of details in the specifications and drawings. We understood that some work would be required to complete the necessary installation details. However, we found it difficult to estimate the level of effort required when the ISC had no experience in dealing with the owner or the owner's design team. It was very disconcerting to wonder if there would be an effective two-way flow of ideas and opinions, or whether details would be rejected without explanation, discussion, and re-negotiation of cost increases over what was anticipated in the bid.

Experience with Contractor's Motivation and Quality

Although profit is the obvious primary motive of any contractor, when pre-qualified to do instrumentation work, he must also maintain his good reputation so that he can do future work. The punitive aspects of the specification (liquidated damages, etc.), which are normally associated with open-bid projects, become the main obstacle that the pre-qualified ISC must confront in the course of a project. Often the ISC perceives that he is in a mad scramble to avoid financial loss on the project, while the owner on the other hand is quick to believe that the contractor is not conforming to the intent of the specifications, in order to gain a financial windfall. In this setting the process of bidding creates adversarial positions. The more punitive the specifications, the deeper the division between the contractor and the owner. Wording which might be considered punitive would require no payment for a instrument that did not function properly after installation. This means no partial payment



Mn/ROAD, Wright County, TX. This retouched photo shows the test section layout for the project. Each section is approximately 500 feet long, with pavement design transitions separating them.

either. The ISC hopes that this is administered fairly during construction, but he has little to go on as the job is bid. If the ISC has no voice in the selection of the instrument, little control over the installation environment, and no control over the action of the prime contractor or other subcontractors after installation, he may not be willing to make a reasonable bid that gives the owner the most for his money. Loading the bid with contingencies to cover uncertainties runs the price up and may price the ISC out of the competition. Partial payment for successful completion of a phase of the project should be written into the specifications, not left up to those who administer the contract.

The project was very successful from the standpoint of instrument performance. At completion of the construction contract, 98.5 percent of the instruments were functioning. Many of the instrument failures occurred during the concrete paving due to the proximity of the top concrete strain gauge to the tamping bar of the paver. A requirement of the design was to place the top strain gauge as close to the top of pavement as possible. This meant one inch below the top of pavement. Unfortunately, the maximum aggregate size was 1.5 inches, and if a coarse aggregate fell on the top strain gauge, the tamping bar of the paver could easily break the gauge as the paver passed over.

Experience with Payment Method

We have had no problems with the method of payment, but suggest that there be provisions for partial payment as portions of the installation tasks are completed.

Other Experiences During Construction

After the bid but prior to the start of work, the owner realized that there were schedule problems, vague or missing specification details, and ill-defined roles. The partnering process was initiated to see if there was adequate commitment from the participants to proceed with the project. Up to that point in time, there was real potential for cancellation of the project because the State was apparently concerned about the potential for extras over unresolved details. For this project, the solution to many of the potential problems was in the partnering process. Partnering developed an environment without adversarial confrontation, and allowed a two-way exchange of ideas that led to rapid resolution of most questions before they turned into problems. Issues were resolved at the lowest possible level, with the ISC's and owner's representatives empowered to work it out in the field. Lower-level management addressed only the questions that could not be worked out by the field people. A delay in a decision is often the largest factor affecting cost, not the details of the decision. If the ISC knows that most decisions will be timely, he will be more agreeable to other concessions that affect his costs. For the partnering process to be successful, the senior personnel for the prime contractor and subcontractors must accept the idea of the partnering process, and be willing to give up authority and accept decisions made in the field, along with the impact that those decisions have on costs.

A pitfall of the partnering process is that some people are slow to adapt. Persons who have spent a long time in construction may be less open-minded. "Why should I make a decision if management will not back me up?" or, "We have been doing it this way for many years." Some feel that the smart contractor adapts to the partnering process quickly and finds a new advantage in dealing with the owner. In this way he can get favorable decisions in the field and still pursue the extras later, whereas in the past the favorable decisions were negotiated in exchange for the extras. Many owners' field representatives have not had the opportunity to develop negotiating skills, and now these skills are important in the partnered project.

The largest issue facing the project was the schedule. State construction people realized this during the partnering process and took the lead in working on this subject with the prime and subcontractors. A commitment to the project developed with most individuals because of the partnering process, and this commitment made the schedule work. Owners' representatives were willing to work on a Sunday to check out instruments to make a scheduled Monday paving date. This would not have happened if the adversarial positions had continued. A subcontractor was less likely to say that it would take two weeks to do an activity if he knew that it could likely be done in one week if he worked a little harder. Personal sacrifice to meet the schedule became a badge of honor for many on the project.

Many questions that came up could be classified as misunderstandings. "What is the intent of the drawing or specification?" or, "I don't think it will work that way" let us know that a new issue was going to require some attention. In most construction projects many of the people involved have years of experience and few basic questions are asked. In the area of instrumentation, few individuals on the project have extensive experience. The discussion about what will or will not work is often based on a person's similar experiences that may apply in a certain instance. People are no less attached to their opinion when it is based on limited experience than when it is based on 20 years of relevant experience. The challenge was to find a way to work out the differences in opinion. An example was how to drill and install instrumentation in the dry if the water table has come up over the winter. Drilling and installing below the water table is not too difficult. However, if the silty sand removed as cuttings must be compacted to the same in-place density without segregation; the owner does not want the water table lowered; and the State has lengthy laws regarding the installation of wells; this task becomes considerably more complicated. Those with little experience in borehole instrumentation simply do not have an informed appreciation for the difficulties such a task presents.

Finally, many unexpected events occur on a project such as this. We discovered that an earth pressure cell "rings" when subjected to dynamic loading at a frequency near the dynamic load impulse from truck axles. We subsequently found that some instruments ring while others do not. As is often the case, the instrument was supplied by the owner, all from the same manufacturer, and the manufacturer had no idea why some of his instruments would "ring." What was the ISC to do here? As it turned out, we developed a laboratory test to detect which cells rang, set those cells aside or used them in the least critical locations on the project, and quickly moved on because cells were needed for paving the following Monday. Naturally, these costs were not anticipated in the bid and were subject to a negotiation for extras.

Other Lessons Learned

The partnering process caused many aspects of the project to be a success that may have otherwise failed. It was also notable that the prime and subcontractors agreed to the partnering process. All participants appeared to realize that they would benefit if the climate on the project was less confrontational.

From the standpoint of the ISC, it is still much better to work directly for the owner. We would prefer to deal with coordination difficulties with the contractor, address standby, detail prime support items, and go through the difficulties in trying to anticipate what needs to be done to reduce the unanticipated extras to the owner, than be in the position of being part of the contracting team.

As a contractor, in situations where a confrontation develops, your loyalties have to be with the team that bid the job and not with the owner. You can try to do the best job you can for the owner, but not at the expense of any member of the contracting team, and in this position the quality of the instrumentation is not the only issue. When the prime says "it is time to dance with the one who brought you to the party," his words cannot be taken lightly.

Superconducting Supercollider (SSC), Waxahachie, TX

Description of Project

Roy F. Cook

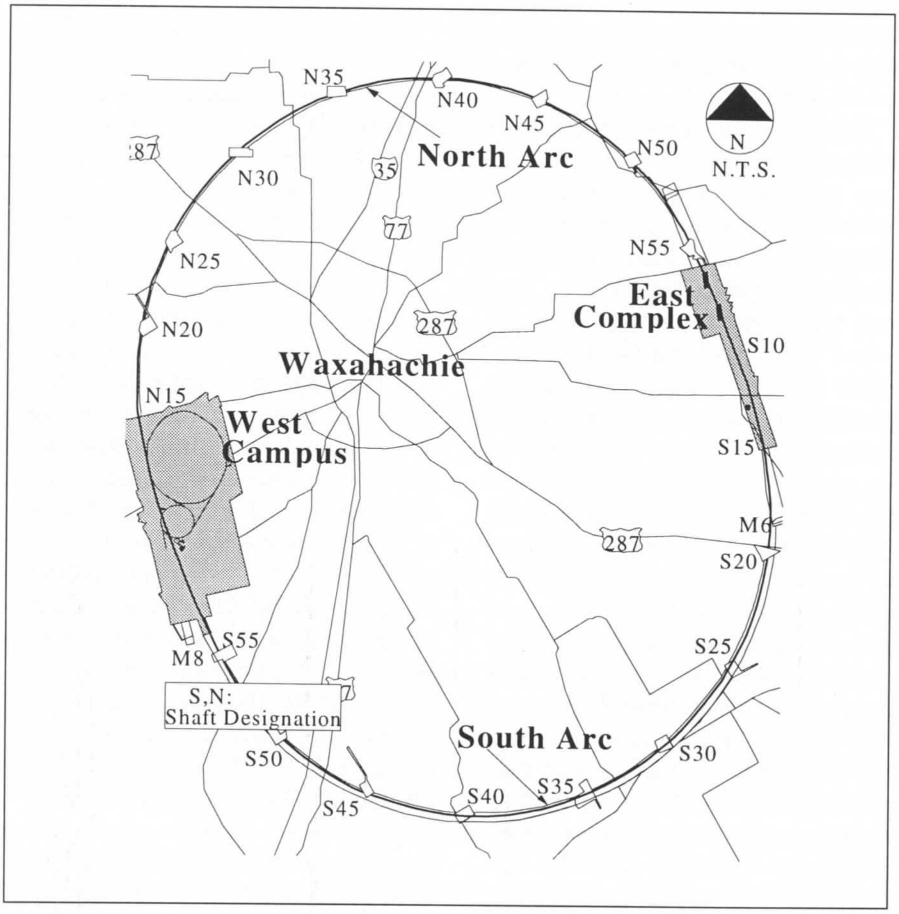
The Superconducting Supercollider (SSC) was a facility for investigating fundamental theories of physics. Its main objective was to conduct subatomic particle research to understand what gives particles mass.

The civil engineering works for the physics experiments included over 70 miles of tunnels, two large underground chambers, over fifty access shafts, and surface infrastructure for a campus housing over 2,000 staff supporting the research activities. The project was located in Ellis County, Texas, about 35 miles south of the Dallas- Fort Worth Metropolis. Its main feature was the collider ring, a race track-shaped tunnel about 54 miles in circumference. The collider tunnel had a minimum inside diameter of 14 feet and lies between 35 and 250 feet beneath the ground surface. Two experimental halls sited at the east complex, were to house large detectors, weighing more than 30,000 tons. Each hall required the excavation of a hole in the ground that was 350 feet long by 120 feet wide by 225 feet deep.

The site geology consists of a belt of shallow dipping weak marine sediments comprising Taylor Marl, Austin Chalk, and Eagle Ford Shale. Surface deposits consist of residual soils developed from the underlying rocks and alluvial soils laid down as stream beds. The underground structures were to be built in the lower 300 feet of the Taylor Marl, 400 feet of the Austin Chalk, and the upper 100 feet of Eagle Ford Shale.

Where possible, the underground structures were planned to be constructed within the chalk. This material is easily excavated and needs minimum support. About forty percent of the underground structures however, were in the marl and shale. These rocks are not self supporting in the long term and provide greater construction challenges.

Despite the generally favorable conditions at the Superconducting Supercollider Project site, subsurface conditions remained uncertain even with an extensive geologic exploration program. There was no local experience to assist with the design of deep excavations in the marl and shale and although these rocks are easily excavated materials, they deteriorate rapidly on exposure.. This raised concerns for the stability of excavations during construction and long-term. Furthermore, in order to limit costs, heavy reliance was placed on the self supporting capability of the chalk and this depended on the competency of the exposed rock in the excavations.



Layout of Superconducting Supercollider

Contract Method

Roy F. Cook and John Dunnicliff

The geotechnical monitoring programs on the SSC Project used two different contractual arrangements. Programs based on bid specifications are described in this section; programs based on professional service specifications are described in Part 3. The first monitoring programs were of the professional services type. As construction progressed and more information became available about field conditions, the client requested, as part of efforts to maintain control of costs, that geotechnical monitoring programs be let on a bid basis. In some cases, where monitoring was used to verify safety during construction, this was a logical step and the monitoring program was included as part of the basic tunnel construction contract on a bid basis. In other cases, where the information was wanted for design verification (i.e., experimental halls) as well as construction monitoring, the programs remained part of the services provided by the PB/MK Team (Parsons Brinckerhoff/Morrison Knudsen), and a professional services type contract was used.

Bid specifications were used for three shafts, a personnel shaft (PS) designated as S-30, and two magnet delivery shafts (MDS) designated as N-55 and S-40. The S-30 shaft was a circular (20 feet diameter) shaft sunk through the Taylor Marl to a depth in excess of 200 feet. This was the first opportunity to investigate the field performance of the marl. As well as determining construction safety, the data assisted in establishing the likely in situ behavior for the large experimental halls. The N-55 and S-40 shafts were large deep elliptical (60 feet major axis; and, 30 feet minor axis) shafts sunk through marl. The programs at these shafts monitored ground movements in order to provide early warning of inadequate support performance and provide data to assist in resolving liability issues that might result from the transfer of shafts between contracts. In this manner, the safety of the construction was monitored during both basic and finish contracts.

As part of the basic construction contract, the tunnel contractors were responsible for:

- Furnishing all instrument components
- Calibrating all instruments
- Installing instruments at designated locations
- Protecting the instruments from damage

- Maintaining and repairing instruments
- Collecting, reducing and processing instrument data
- Interpreting and reporting instrument data.

We specified detailed requirements that were minimum criteria for such items as instrument components, calibration, instrument locations, reading frequency, and reporting. We maintained the quality of the programs by stipulating minimum requirements for each activity. The requirements covered all aspects of the geotechnical monitoring program including the specifications for the hardware, the qualifications of personnel, reading frequency, and methods for reporting data in both electronic and hard copy documentation form.

The tunnel contractors had the responsibility to coordinate site activities. This gave them the opportunity to minimize interference with construction activities. They also had the responsibility to interpret data and report unusual conditions. The tunnel contractors generally sought the services of a geotechnical specialist subcontractor to perform the actual work including the interpretation of the data.

To interpret the instrument readings, the specifications included criteria for each instrument. The criteria gave threshold levels, generally in terms of deformations and deformation rates that once exceeded required action by the contractor. The criteria were developed from engineering analyses, generally based on simple closed form solutions although two and three dimensional numerical analyses were used for the more complex structures. An important element of the program was the preparation of a plan of action to mitigate conditions should the criteria be exceeded. This was the responsibility of the contractor. The following wording related to criteria for threshold levels:

If criteria are reached, the contractor may be required to initiate one or more of the folowing response actions as directed by PB/MK.

1. *Increase instrument monitoring frequencies.*
2. *Install and monitor additional instruments.*
3. *Modify construction procedures, including the installation of additional shotcrete and rock dowel support.*
4. *Submit proposed plan of action for remedial measures to control the excessive deformations*

The specifications did not establish payment associated with the response actions to be initiated if the threshold criteria were exceeded. It was anticipated that this would be dealt with on a case-by-case basis following an investigation to find out why the threshold was exceeded. Anticipated reasons include differing site conditions, field performance that violated the design assumptions, or poor construction.

General geotechnical instrumentation requirements were paid for under a lump sum item in the contract. This included:

- Readout units and installation equipment
- Collection, reduction, processing, plotting and reporting of data in accordance with the monitoring schedule provided in the specification
- Protection of installed instruments, and repair or replacement of damaged instruments
- Field calibration and maintenance
- Storage and disposition of instruments
- Interpretation of data.
- Provision of readout units and access to instruments on an as needed basis to PB/MK.

Other aspects of the program, the instrumentation materials and their installation, were paid for on a unit price basis. Inclinometer casing and rods for multiple position borehole extensometers were measured by linear foot with clearly defined physical limits prescribing the basis for measurement. Convergence gage reference eyes and multiple position borehole extensometer heads were measured by each installed and complete in place. Instrument readings, beyond those required by the schedule were paid by the hour.

Experience During Construction: Owner's Representative Roy F. Cook

Role of Author's Firm

The PB/MK Team planned the geotechnical monitoring program and put together the contract documents. The program was complete and included all aspects such as location of instruments, types of instruments, reading frequency and reporting requirements. Once the contract was let, our role was one of oversight. We reviewed submittals of materials specifications, and installation and reading procedures; we provided inspection services of instrument installations; and, we reviewed the data and reports provided by the geotechnical firms. Unless the threshold criteria were exceeded, PB/MK geotechnical personnel were not actively involved in field monitoring.

Experience with Contractor's Liability/Responsibility

The main tunnel contractors had the responsibility to install geotechnical instrumentation at specific locations and read it according to an agreed schedule. The contractors were responsible for interpreting the field data and for making plans for remedial actions in the event of unexpected conditions. The monitoring programs were under the control of the prime contractors but actual work was subcontracted out to geotechnical specialist contractors. PB/MK provided oversight to ensure that the programs were carried out to the standards specified.

In the end, only one condition was encountered during construction (at the S-40 MDS) that needed corrective action. It was dealt with without impacting construction activities or schedules. Had more serious unexpected conditions developed, the responsibility for remedial measures would have depended upon circumstances. The parties involved in establishing the suitability of any remedial action would have included the tunnel contractor, the geotechnical firm, the PB/MK construction management, and PB/MK geotechnical and design personnel. However, the specifications were clear in that it was the responsibility of the prime contractor to initially prepare the plan of action for approval by PB/MK.

Experience with Contractor's Motivation and Quality

The installation of instruments was performed by the geotechnical firms in accordance with specifications and was generally carried out to high standards. With instruments in place, there was a tendency for some prime contractors to try to minimize costs. They negotiated for reduced reading frequency, and where possible, they used their own personnel to take readings rather than retain the geotechnical firms on site. We had concerns with this approach since personnel taking readings were sometimes not experienced. We felt that this could lead to reading errors; that more experienced personnel might identify subtle indicators and provide earlier warning of problems; and, that the geotechnical firm's personnel interpreting the data off site would be unfamiliar with site conditions. Given these concerns, it was not clear that the prime contractor had fully understood the extent of his responsibility to interpret the ground movements.

Experience with Payment Method

The payment method worked well as long as the actual monitoring program did not deviate significantly from that proposed at the design stage. However, where the contractor elected to use an excavation or construction technique that modified the program, difficulties were encountered. This was especially true in setting up and pricing new reading schedules that allowed the contractor to take full advantage of his construction technique while still providing the field data for design. This was most evident at the S-30 Personnel Shaft where a drill rig was used to bore the shaft in several passes rather than excavate by conventional means. Changes to the schedule of readings required agreement among five parties, the prime contractor, the shaft drilling contractor, the geotechnical firm, PB/MK construction management, and the PB/MK geotechnical design group. Further negotiations were required to adjust the payment schedule to reflect the revised monitoring program.

Other Experiences During Construction

In the event, only one case was encountered where field measurements exceeded the threshold limits. This occurred at the S-40 MDS. During shaft excavation, lateral deformations exceeding threshold levels were measured by one inclinometer. The movements were in the weathered Taylor Marl just above the transition to fresh marl. The excavation through the weathered marl was supported by liner plate reinforced with ring beams with grout injected behind the liner plate to fill the voids. Incomplete filling of voids had caused the ground to move but secondary grouting stopped further movements

Lessons Learned

The bid method worked well and produced quality work carried out within budget. We credit this to the effort that went in to the preparation of the bid documents as well as to the professional approach adopted by the contractors, both the main and the geotechnical firms. The bid method significantly reduced our coordination efforts and contract costs reflected the low bid basis for the work. This increased our efforts in overseeing the quality of the work. On occasion, geologic conditions warrant changing monitoring programs. This contractual approach lacked some flexibility and negotiations were needed between several parties, in order to change the monitoring program to meet changed requirements.

We did experience some difficulties in transferring data electronically. The geotechnical firms were responsive to our requirements and sent hard copies of data rapidly. We had trouble receiving data by modem. In future, we would give more thought to computer and software compatibility through the specifications.

Experience During Construction: Subcontractor Eric Eisold

Role of Author's Firm

Woodward-Clyde (W-C) provided instrumentation services during the construction of the N55 MDS and the S30 PS as a second tier subcontractor on the SSC in Waxahachie, Texas.

W-C was subcontracted to a joint venture of the Gilbert Texas Construction Company and J. F. Shea (G/S). The projects consisted of excavating tunnels and shafts for the planned SSC. The tunnels and shafts were located primarily in the relatively soft rock formations of the Taylor Marl and Austin Chalk of Cretaceous age. The depth to the tunnels was on the order of 200 feet.

The specified purpose of the instrumentation was to:

- "...provide data from the S30 PS as input to the future design of the Interaction Halls."
- "Pre-construction baseline data for comparison with construction and post-construction data."
- "A forewarning of unforeseen conditions that may require remedial or precautionary measures."

The instrumentation specified consisted of inclinometers, probe extensometers, multiple position borehole extensometers (MPBX), tape extensometer points and vibrating wire strain gauges.

W-C performed the role of the Geotechnical Instrumentation Subcontractor (GIS) and provided instrumentation services including preparation of submittals, drilling, installation and monitoring of the specified instrumentation. Assistance with optical survey and drilling for the MPBXs and tape extensometers was provided by G/S.

It should be noted that similar specifications for instrumentation were included in the construction contract for the S40 MDS and that the construction contractor on that project played a more active role in collecting and reporting data while the GIS played more of an oversight role.

Experience with Contractor's Liability/Responsibility

The contracts negotiated between W-C and G/S were based on a standard construction type subcontract typically used by the prime contractor to procure construction trade contractors. Important provisions of the subcontracts included:

- Liability on the part of the subcontractor for the performance of specified work including any delays due

to the subcontractor's work
- A performance bond in the amount of the subcontract
- Certified payroll of subcontractor's personnel
- A ten percent retention of all payments made to the subcontractor

The certified payroll aspect of the subcontract did not really apply because the project personnel assigned to the projects by the GIS were professionals, not trade labor. W-C would have preferred to use a professional service contract for the work, but the form of contract used was workable with some additional provisions including clear definition of the scope of work, assumed construction schedule and a due professional care clause.

Experience with Contractor's Motivation and Quality

The subcontracts for instrumentation services on the S30 PS and the N55 MDS projects were awarded by the prime contractor solely on the basis of price from bids and subsequent negotiations with presumably qualified engineering firms. In my opinion, it would have been difficult for PB/MK to reject marginally qualified firms from serving as the GIS on SSC projects if the prime contractor had a good subcontract bid price and advocated for their approval.

The quality of the work on the projects was aided by the detailed instrumentation specifications included in the construction contracts. The specifications did a good job of specifying quality products and materials, installation procedures and data collection and monitoring procedures. However, due to the cost constraints of being the low bidder on the project, I had to be very careful in scoping the work required to be provided by the GIS. I had to make assumptions about the behavior of the anticipated subsurface materials including borehole stability and anticipated movements of the subsurface materials in response to the excavations. In preparing the bid, I was very optimistic about the stability of the materials and G/S's construction schedule.

W-C staffed the project with a single experienced senior staff level engineer. His effort required lots of overtime to fulfill the minimum requirements of the specifications. It would have been better to have two GIS project personnel on site during construction. This would have increased the amount of quality time spent on data analysis and timely reporting, especially in the event of an unanticipated movement detected by the instrumentation that could have effected the stability of the excavations. Had I included a second field person in our bid, W-C would not have been awarded the GIS subcontract on the projects.

W-C was very fortunate that G/S elected to have the GIS on-site to supervise and/or install all instrumentation installations and perform all data collection and reporting. The specifications did not require the GIS to perform all these duties. If G/S had elected to have installations of only first instruments and first data collection performed by personnel other than W-C's, we would have had a difficult negotiation to define the limits of liability to be assigned to the parties involved in the subcontract. It would also have inhibited the timely analysis and evaluation of data collected.

Experience with Payment Method

Payment to the GIS was based on:
- Measurement of approved installed instrumentation including labor and materials for the monthly progress payment period used by the prime contractor
- Measurement by percent of work completed towards the lump sum subcontract price for general requirements related to monitoring and reporting of data as specified
- Payment at the subcontract price by the hour for additional data collection and reporting as directed by PB/MK (N55 MDS). No additional monitoring was requested.

W-C submitted monthly invoices which reflected costs of the work performed as a percentage of the total subcontract amount. G/S broke down the invoice amounts into the unit items identified in the prime contract. In retrospect, W-C should have done the unit item breakdown for each invoice submitted. Progress payments submitted to PB/MK by G/S for work performed by the GIS always reflected the correct amount but, in some cases, apportioned the work performed in an incorrect unit item. Subsequent corrections caused inefficiency in subcontractor payments. Approved progress payments typically were made to the GIS at about 90 to 120 days following submittal of an invoice. As of the date of this report, no retention has been paid to W-C for either project.

Other Experience during Construction

It was our experience that the GIS was expected to be available twenty four hours a day to collect data depending on the construction schedule. Adequate support was provided by G/S, however it was quite clear that data collection was in no way to interfere with the construction operations of the shafts. The GIS was a subcontractor performing work on a construction contract and was expected to behave like a contractor. This may take a little getting used to for our profession, but it is likely to be the most common way in which instrumentation services will be performed on projects in the future.

Lessons Learned

It has been my experience that instrumentation requirements as well as QA/QC responsibility are increasingly being included in construction contracts. In my opinion there are two primary reasons for this phenomenon:
1. To reduce the proportion of design and construction management costs compared to construction costs and
2. A perception that total project costs will be less if construction phase engineering services are procured through the construction contract.

If indeed, this is the trend in procuring such services, it will be crucial that project specific, thoughtful and detailed requirements for instrumentation be written into the construction contract documents. Other lessons learned include:
- Potential instrumentation subcontractors will have to be very careful in developing the scope of their responsibilities in the subcontracts.
- Contract terms and payment conditions will likely take the form of construction type subcontracts.
- Project suspension and termination

clauses in the subcontracts should warrant increased consideration during negotiations to provide for timely reconciliation of final payments and retention.

- Engineers working on construction contracts will have to behave more like contractors and less like professional service firms, including going for the low bid and subsequently filing for change orders and claims.

In general, I feel that it is inappropriate to procure the services of a professional engineering firm to provide instrumentation services during construction through the construction contract as if though they were manufacturing widgets. Geotechnical instrumentation is an important technical aspect of the project which can have a significant impact on the cost and construction of a project. The level of effort required during construction can vary significantly depending on the circumstances and experienced high quality professionals are generally not going to be procured through low bid subcontracts.

Professional service needs that are required during the construction of a project would best be met by negotiating a contract with the responsible design firm. This would result in less conservative and more innovative design. The design engineer can also make decisions during construction regarding design issues resulting in fewer change orders and claims. It can be argued that the cost for change orders and claims arising during construction far exceed any additional costs for professional services rendered during the construction phase of a project.

Now for the last part of my sermon. If it is the intent of procurement departments of various big agencies, both private and public, to optimize the cost and quality equation when designing and building projects, then I submit that two basic and major improvements be made in analyzing the process of building projects:

- Life Cycle Analysis (LCA) - This process is being used increasingly by major manufacturers around the world in determining how the overall process of creating widgets, bringing widgets to market, using widgets and disposing of widgets can be accomplished more cost effectively and while reducing risk. Each step in the process is analyzed and compared to the other steps to create a big picture approach to evaluating the process. The same approach should be utilized in designing and constructing projects.
- Quality Based Selection (QBS) - If professional service firms feel that their contribution to projects deserves special consideration in the procurement process, then construction contractors should feel the same way. Indeed, some of the brightest and most innovative ideas for building projects have come from contractors, not professional service firms. Unfortunately, the best and brightest can not usually compete on a low bid basis. We depend on such conventions as the "Value Engineering Change Proposal" (VECP) to bring such innovation to the benefit of projects; or we litigate change orders and claims to increase the construction contract price. Engineers and contractors should be procured by QBS methods and price negotiations should start with the top ranked firms.

Experience During Construction: Subcontractor Hanson Bratton

Role of Author's Firm

NTH Consultants, Ltd. was retained by Traylor Brothers/Frontier Kemper (TB/FK), the prime contractor for the S40 to S55 Tunnel portion of the Superconducting Super Collider Project (SSC). NTH's contract included the work required to implement the geotechnical instrumentation program for the S40 Magnet Delivery Shaft as a part of the contract, as detailed in the project specifications. Our scope of work generally included the preparation of the associated submittals, procurement of instrumentation, installation of instruments, training of data acquisition personnel and data processing.

NTH was aware that TB/FK's contract had Disadvantaged Business Enterprise (DBE) requirements. To use this requirement to our bidding advantage, we subcontracted with Van & Sons' Drilling Service, Inc., a local DBE drilling firm we had previously used for other projects. This would allow TB/FK to meet a significant part of the DBE requirements by contracting with our team.

As an out-of-state firm, we could not possibly compete on a strictly monetary basis with the local firms or other firms already involved with the SSC. In addition to using the DBE requirements to our advantage, we decided to use an approach we had successfully developed for a previous contract NTH had at the Boston Harbor Project. This approach incorporated the use of less expensive contractor personnel for the instrumentation program on less technically sensitive tasks. This can reduce the contractor's overall cost by using his personnel already available on site instead of subcontractor personnel. In particular the task of obtaining instrumentation readings can often be performed by properly trained contractor personnel. We have found that contractor surveyors are very good candidates for these tasks since they are generally trained to maintain a level of accuracy. However, the subcontractor must maintain methods of assuring that quality is being maintained by the contractor personnel. This is critically important in convincing the owner/engineer that using the contractor personnel is reasonable and will not compromise the quality.

Experience with Contractor's Liability/Responsibility

The contractor was required to procure, install, maintain and monitor the instruments, interpret the data and also to provide processed data to the owner/engineer.

As indicated previously, we were utilizing contractor personnel to monitor the instruments. We were comfortable that our review of the data as they were being processed could readily determine if the contractor's personnel were performing an adequate job. If data were questionable the contractor would be directed to re-read particular instruments.

In addition, a fortunate arrangement on this project was that NTH was allowed to communicate directly with the owner's representative, the PB/MK Team. We had direct access to the engineers interested in the instrument results. This allowed any difficulties or concerns for the program to be addressed by the people most familiar with the technical principles.

Experience with Contractor's Motivation and Quality

Since NTH was not on site full-time, we had to be particularly concerned with the contractor's motivation and quality of work. We have found from previous experience that educating the contractor about the program is of great importance. We also stressed that taking the program seriously can greatly reduce confrontations with the owner/engineer that could impede production on the project.

Although on this project TB/FK seemed to be relatively well motivated, NTH had to continually contact the contractor with regards to scheduling matters. If not, extremely short notice could be expected to mobilize for instrument installations or contractor personnel could miss a set of readings.

Experience with Payment Method

The contract amount we submitted with our bid to TB/FK was a lump sum figure. We detailed the scope of services for which the lump sum amount applied and also included the assumptions we had used in developing the figure. It was made clear that the scope of services met the requirements of the project specifications. Our experience with contractors is that in general they feel much more comfortable with lump sum budget figures. Oftentimes marginally higher lump sum quotes are more readily accepted than a lower cost estimate for payment on a time-and-materials basis. Obviously this creates a level of risk to the subcontractor, but the key is to detail the scope of services and the assumptions in the bid. A schedule of values was agreed to with the contractor and our invoices were submitted on a percent complete basis.

Lessons Learned

In large part, the instrumentation program was a success. It did require a great deal of effort to coordinate with the prime contractor to make sure the project specifications were being met. Generally, contractors do not consider these programs to be of primary importance in the construction of the project. The subcontractor must continually communicate with the contractor, sometimes reminding him of particular specification requirements. As a result, the subcontractor must be ready to respond on a moments notice to meet the needs of the contractor. This is just the nature of the business.

Megabuck Tunnel

Charles Daugherty

Description of Project

Megabuck Tunnel constituted the initial 20 percent of a system slated to eventually extend for more than 20 miles beneath a major American city. It was divided into more than half a dozen contracts of varying length, and constructed in the late 1980s and early 1990s by five low-bidding prime contractors. Megabuck was comprised of 20-foot diameter mined tunnel headings separated by several reaches of cut-and-cover construction. The cut-and-cover portions were mostly supported by soldier piles and lagging, supplemented with tiebacks or internal bracing. Initial mined tunnel support was at the contractor's option, with final lining consisting of cast-in-place concrete. Because all of the construction was in soft ground, relatively shallow, and either overlain or closely flanked by vulnerable cultural features, the monitoring of ground movements and support system stresses was considered of prime importance.

Contract Method

The owner chose to use a bid specification for materials and field instrumentation services. The materials specification made use of brand names and "...or equal to..." type descriptions. The owner's reason for handing responsibility for instrumentation to the contractors was that this would preclude having to deal with a variety of separate installation bids and procurement processes. Each prime contractor would be responsible for all aspects of his particular project. There was also the thought that, with the instrumentation personnel working directly for the prime contractor, interference between the two entities would be minimized.

Experience During Construction: Owner's Representative

As is common in this type of arrangement, the construction management (CM) firm was budgeted to retain a small geotechnical staff tasked with reviewing instrumentation subcontractor qualifications and proposals, monitoring the flow of data, performing independent analyses or interpretations, and taking check readings to confirm data accuracy. Due to the way specifications were written, the CM geotechs had to purchase their own monitoring devices for the check readings. This somewhat reduced the flexibility that might otherwise have been offered to the various instrumentation subcontractors, because it was then necessary to install only instruments that could be monitored by means of the CM's readout units. This was the least of the problems created by the established arrangement. More serious difficulties included:

1. In most instances the CM geotechs, generally the only CM oversight forces qualified to review the data, received it very late. Although specifications were tight in their stipulations of monitoring, analysis, and submittal schedules, there was too much lost motion in the circuitous path the data had to follow. The instrumentation subcontractor had to submit his findings to his client, the prime contractor. The findings might routinely lie on the desk of the

contract project manager (PM) for some time before being passed on to the resident engineer (RE). This period could easily be stretched out if the PM did not agree with whatever his subcontractor had developed. Then, the material could lie on the desk of the RE for another period of time before being sent on to the CM's geotechnical department. It was not uncommon for data with a specified submittal schedule of 24 to 48 hours to require more than a week to reach the CM geotechs. Only in some instances was it possible to arrange immediate data transfers by having a daily meeting between the instrumentation subcontractor, the PM, the RE, and the CM geotech.

2. In addition to the problem of data transfer, it was all too common for too little data to be developed in the first place. In many instances the specified monitoring schedules were not adhered to, and only a token effort to analyze the results was made. A major reason for this lack of enthusiasm lay in the fact that the work was obtained on the basis of a low bid. The prime contractor, a low bidder, became so partly by coaxing the lowest possible quotes from his various subcontractors. Low bidders are not famous for doing everything exactly by the book; the low profit margins simply do not permit it. This sometimes became critical during periods of excessive or accelerating ground movements, when a tightened schedule of monitoring was required but not always achieved. Often, a low bidder is prone to assume while bidding that there will be no problems requiring additional work and then to dig in his heels against action when rosy projections prove false.
3. Even conscientious subcontractors were often stymied in their efforts to install instrumentation or to take readings. For example, the mounting of strain gages on a pipe strut could be very difficult when the instrumentation subcontractor was not kept properly informed of probable installation schedules. Likewise, the reading of particular instruments sometimes proved impossible when the prime contractor refused to move obstructing materials or vehicles. The reason for such recalcitrance is that many contractors consider instrumentation a nuisance item with limited importance. The installation and monitoring of instruments is perceived as being a hindrance to the real work being done, a hindrance with few positive mitigating features. In at least one case in the Megabuck Tunnel, this attitude was shared by the RE, a circumstance that made it even more difficult to enforce the specifications.
4. A not uncommon problem for the CM geotechs lay in the cozy relationship that sometimes developed between the construction contractors and the resident engineers. The contractors and their specialist subcontractors, by specification, had the primary responsibility for instrumentation and, at least to some REs, this seemed to relegate the RE's own geotech support staff, (who answered to a different superior) to the status of nagging kibitzer. The geotechs **were** "nags" in that they pressed hard to have specifications strictly adhered to, and strict adherence always means more effort, not welcome to a low-bidding contractor or subcontractor or to an RE struggling to get along with them. On a construction site the RE is there to see that the total job goes forward with some degree of coherence, while the geotechs must retain a certain degree of tunnel vision and push hard to see their more limited concerns properly addressed. This is a natural setup for some amount of conflict, and on Megabuck, the geotechs were at a disadvantage from having had so much of their function handed over to the contractors.

   In the worst example of this type of conflict, the contractor simply refused to believe the evidence that his excavation was in some distress, although the CM geotechs were trying to call attention to the developing situation. The RE preferred to believe the contractor's analysis, and took no firm action until several weeks after the problem first surfaced. The distress finally resulted in the disruption of a major thoroughfare at a cost of millions of dollars in delays and added support. There is no way of proving that an earlier establishment of cooperation among contractor, RE, and geotech would have averted the ultimate near failure, but it is certain (at least in my mind) that the developing problem would have been addressed much sooner if the CM geotechs had had more authority to press their views.
5. The most serious problem to develop in the handling of Megabuck instrumentation was the appearance of one completely unqualified subcontractor firm (hereinafter referred to as Firm X). Even with specifications governing qualifications tightly written, it was possible for the inexperienced firm to assemble a resume that was difficult to cross-check or to refute, especially in a time and place where there was political pressure for such firms to be retained. To make a bad situation worse, this "specialist's" client won several contracts and ended up with the lion's share of construction work. From the beginning, Firm X was in a learning rather than a "doing" mode, and never displayed much aptitude for either part. Late in construction, their continuing ineptness was so blatant that it was finally possible to have a hearing to discuss the subject among representatives of the owner, the construction manager, and the prime contractor. However, even in the face of overwhelming evidence that Firm X was not qualified to continue in their work, it proved politically infeasible to remove them. Instead, it was decided that Firm X would be retained but "demoted" to the role of instrumentation data reducer/interpreter, while the prime contractor took over the monitoring. This was completely counter to the specifications that required monitoring, reduction, and interpretation to be performed by an experienced specialist, but such is the way when technical/contractual decisions have to be tempered by political considerations.

Lessons Learned

The above should not be taken to mean that all of the Megabuck instrumentation was an unmitigated failure. At least two competent firms were retained as instrumentation subcontractors and some good work was accomplished in spite of all of the conflicts and competing pressures. However, from my perspective, it would have been better to have most aspects of the instrumentation under the control of a single entity answering directly to the owner.

There is presently a school of thought that says contractors have a right (perhaps an obligation) to control all aspects of instrumentation because it is they who have primary responsibility for construction safety. Does the Megabuck experience attest to the validity of this argument? I think not. Construction was fraught with danger in that damaging ground settlements could so easily develop, yet most contractors chose to downplay the chances and the indications of it happening. The system of permitting a contractor to receive construction data and advice from a cost-cutting, contractor-influenced subcontractor - sometimes a substandard one - was akin to a system wherein fearful or overconfident medical patients would be permitted to bend a low-bidding physician to their will.

Everyone's interests would have been better served had the contractors been receiving their primary instrumentation input from a single, highly-qualified, project-wide source that was gaining in knowledge by seeing developments throughout the four-mile system rather than on one or two contracts. Such a source would logically have been under contract to the owner. It would have been more thorough in its development of data by dint of being less easily influenced by an inexpert client (or by a client with a vested interest in seeing or admitting no problems). And such a source would have been responsible for all aspects of instrumentation data collection and interpretation, up to the point of determining how increasing movements or stresses compared with predetermined response values, at which time the contractors would still be required to exercise their responsibility for safety by making the final interpretive leap and deciding whether to take corrective action.

A switch to CM controlled monitoring was made after the Megabuck experience and there was a marked upturn in the effectiveness of geotechnical instrumentation in the remainder of the tunnel system.

Contract Practices for Geotechnical Instrumentation Part 3 - Professional Service Specifications

Introduction

John Dunnicliff

This part of the series of articles includes projects listed in Tables 4 and 5 for which procurement of materials was or will be the responsibility of the design consultant, and field instrumentation services were or will be provided by a geotechnical engineering consulting firm selected by and contracting with the owner, with payment on a professional services basis.

The sequence of projects is based on chronological order.

Mount Baker Ridge Tunnel, Seattle, WA

Gordon E. Green

Description of Project

The Mt. Baker Ridge highway tunnel bore, constructed in 1983-85, in Seattle, WA, provides 3-level traffic access within a 63.5 ft (19.4 m) inside diameter, 1332 ft (406 m) long tunnel. The "stacked-drift" method was used to build the liner segments, starting at the invert drift, to complete tunnel liner construction prior to mass excavation of the interior.

The design team was headed by Howard, Needles, Tammen and Bergendoff with Shannon & Wilson (S&W) responsible for geotechnical and underground engineering and instrumentation, and Jacobs Associates responsible for cost and schedule. The owner, Washington State Department of Transportation (WSDOT) also had the services of a tunnel review board comprised of Dr. Ralph Peck, Mr. Al Mathews and Mr. Chuck Metcalf. The contractor was Guy F. Atkinson (GFA).

Extensive instrumentation was required due to the unprecedented tunnel size, unusual construction method and urban location with overlying houses and streets. Specific reasons for monitoring included:

- assessing portal access pit stability
- maintaining ground loss control in drifts
- limiting damage to overlying and adjacent structures
- checking design assumptions and tunnel and access pit performance
- assessing contractors' construction procedures

• providing data for dispute resolution

A cross section and instrument types are shown on the figures. Details of the design, construction and performance as viewed separately by (a) the structural designer, (b) the geotechnical and instrumentation engineer, and (c) the prime contractor, are contained in the references.

Contract Method

Instrument Type	Quantities	Number Working Properly After Construction
Inclinometer casings (Sinco)	62 casings (9,350 ft)	94%
Settlement rings Sondex (Sinco)	1772 rings on casings	94%
Borehole extensometers (Irad)	5 units 3 position sonic probe	100%
Concrete stressmeters (Carlson)	72 resistance gages	94%
Jointmeters (Carlson) (Geokon)	20 resistance gages 81 linear potentiometer gages	80% 95%
Tape extensometer points (Sinco)	121 anchor points	100%
Vibrating wire strain gages (Sinco)	192 weldable gages	96%
Survey points	309 surface leveling points	83%

The contract for the Mt. Baker Ridge tunnel bore included most of the innovative risk sharing contracting methods currently being used in underground engineering and elsewhere. This included a design summary report, construction methods report, disputes review board, risk sharing for cost inflation, escrow of the contractor's bid calculations, and acceptance of all settlement damage by the owner.

The extensive instrumentation system was designed by S&W, who also wrote the specifications for materials and field instrumentation services, prepared detailed order lists for materials and, with WSDOT, negotiated prices with selected instrument manufacturers. S&W also installed certain instruments, guided the installation of certain other instruments by the contractor, trained WSDOT crews in monitoring and maintaining instruments, processed and interpreted all collected data and issued regular status reports to WSDOT. All of this work by S&W was performed on a professional service basis.

Care was taken in writing the materials and field instrumentation services specifications to be clear, exact, equitable and complete. Instruments and manufacturers were selected by S&W on the basis of quality, experience, suitability and a manufacturer's reputation for a particular instrument. Price was a minor factor since cost differentials between candidate instruments were small, whereas quality and performance were critical. Most North American instrument manufacturers were represented and the low bid arena was avoided.

The prime contract documents included a detailed generic description of the instruments, installation procedures and division of responsibility for installation. Instrument specifications were not included, only a general description sufficiently detailed for the bidders to understand what was required of them. Some instruments were installed wholly by the contractor, e.g. inclinometer/ settlement casings, and others with crucial stages performed by the engineer, e.g. electrical connections of concrete stressmeters at junction boxes. Other instruments, e.g. vibrating wire strain gages, were installed by S&W, with defined support services provided by the prime contractor, e.g. access, turning over beams, protective pipe. Estimates of time for S&W's installation tasks were included in the prime contract documents.

Instruments were purchased on an assigned supplier basis. For bidding purposes a $259,000 line item for furnishing instrumentation materials was included. A separate unit price line item was included for each type of instrument to cover either complete installation or support services. Boreholes for inclinometers and extensometers were bid separately on a per foot basis.

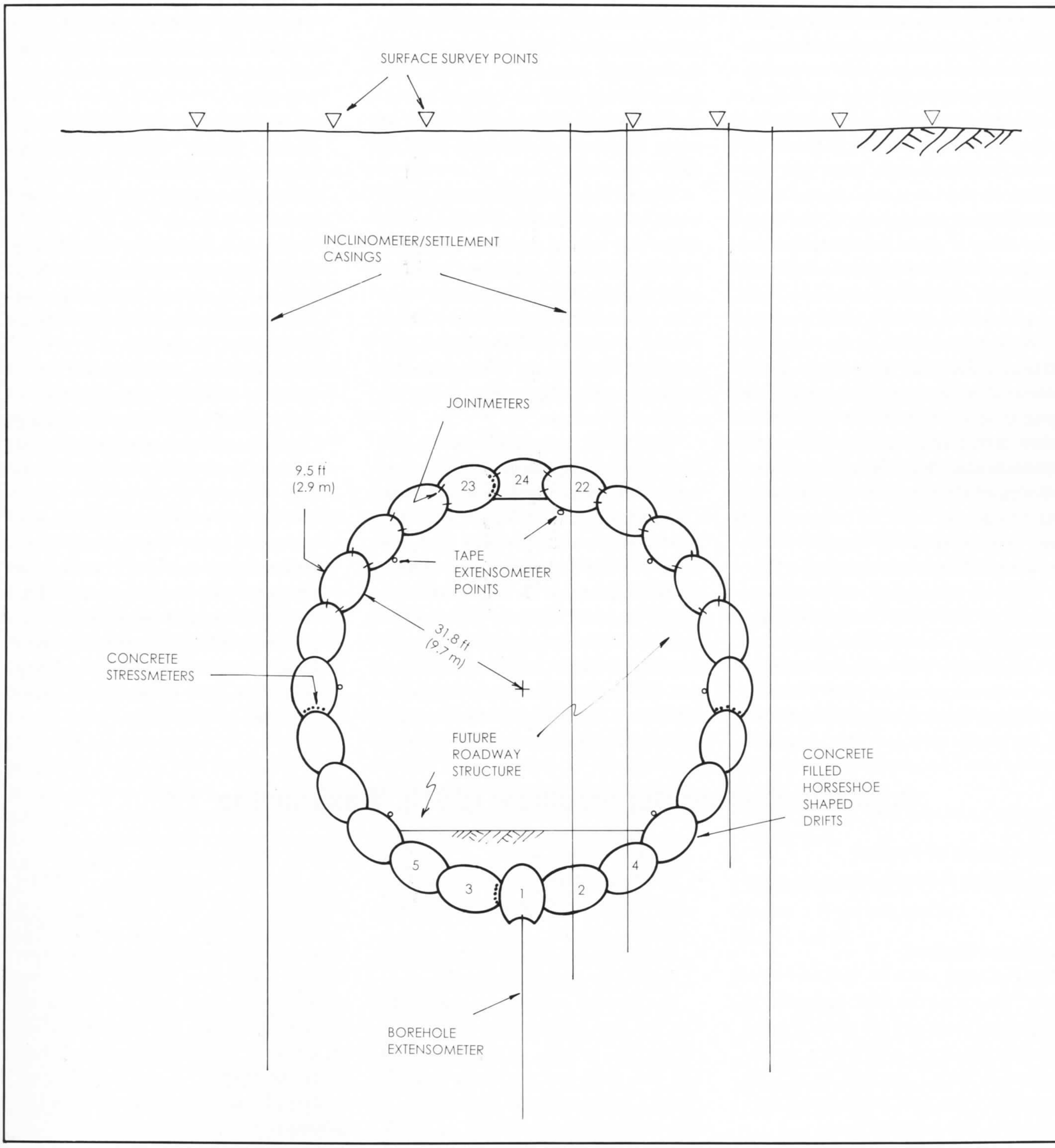
The contractual arrangements for field instrumentation services were selected based on the qualifications of the already onboard geotechnical and underground engineering consultants (S&W); the owner's desire and ability to perform all monitoring; the contractual need to limit ground movements around drifts and need for rapid data analysis and interpretation by best qualified persons. The prime contract stated that all raw instrumentation data obtained by the engineer would be made available to the contractor within one working day, and all analyses and current interpretations within four working days. The contractor was allowed to select his own method for constructing the 24 concrete filled drifts but was required to limit movements around individual drifts to one inch vertically and half an inch horizontally. These limits were exceeded during construction of drifts #2 and 3 when the job was stopped. Monitoring data were important in resolving problems that led to improved temporary drift liner expansion and grouting procedures.

Experience During Construction

The prime contractor selected a local MBE firm, Hong Consulting Engineers (HCE) to install instruments for which the contractor was responsible, and to provide some of the required support services. In view of HCE's limited instrumentation experience, additional guidance and training was provided by S&W field instrumentation engineers during installation of some instruments.

Strict location and initial verticality requirements were specified for inclinometer casings (200 ft + deep), for proper location relative to the tunnel drifts. Although potentially a cause for considerable conflict, only one installation out of 62 was re-drilled, largely due to the skills of the driller who had previous experience at the site. The driller's subcontract bid price may not have been the lowest. Inclinometer casing verticality and spiral was checked by the contractor prior to acceptance of the installation.

Jointmeters between drifts were not included in the original contract, but were added after excessive movements above the first few drifts created heightened concern about drift joint performance. Initially Carlson resistance gages were installed, as the only option readily available. Concerns on S&W's part



Mount Baker Ridge Tunnel. Instrumented Tunnel Section about their performance led to developing a new jointmeter in conjunction with a selected manufacturer, Geokon. The flexible contractual arrangements (assigned supplier for materials and professional services contract for S&W) allowed this change to be handled easily and the improved instrument performance was beneficial and cost effective.

The contractor was required to limit deformations around the drifts by controlling construction methods, based on measurements made by the owner, using instruments installed by the contractor and processed and interpreted by the engineer. All parties worked well together, respected each other and conflicts were minor. Instrument installations and readings in the drifts were done at times which minimized disruption of the contractor's work and sometimes required inconvenient work schedules. Since S&W, HCE and the owner's staff were all locally based, additional skilled staff were always available at short notice to work around the contractor's schedule. All instruments were monitored with intelligent readouts or electronic clipboards and data were generally transmitted by the owner via a modem to S&W for computerized data processing using custom written programs, interpretation and reporting.

The instrumentation was an integral part of an innovative tunnel construction contract, accomplished in a climate of cooperation with minimal conflict. The instrumentation program benefited from the enlightened risk sharing format of the prime contract. The program's split responsibilities required that all parties work together, in some cases side-by-side in the restricted drift workspace. Instrument order lists had to be prepared by S&W in sufficient time for processing through the owner to the contractor and his instrumentation subcontractor and still give suppliers adequate lead time. The interaction required by the form of instrumentation contract encouraged active participation and cooperation. This is in contrast to the frequent outcome of a single line lump sum bid item for "supply and install instruments" frequently found in many construction contracts, even today.

The Mt. Baker Ridge tunnel is the world's largest diameter soft ground tunnel and was awarded the 1990 Outstanding Civil Engineering Achievement by ASCE. The tunnel bore contract was completed ahead of schedule and $2 million below the $38 million bid price. The project is considered a model example of equitable risk sharing contracting practice.

Well qualified, enthusiastic staff were generally involved at all levels of the instrumentation program. This was a high profile, challenging job, executed in what some would consider the home town of field instrumentation design and development in the US. Good cooperation occurred between owner, engineer and contractor and everybody benefited. Reliable tunnel performance data was acquired in a timely manner to aid critical engineering decisions. A high percentage of the instruments were working properly after construction was completed. The Mt. Baker Ridge tunnel demonstrated the effectiveness of performing a field instrumentation service program primarily on a professional services basis, and not bidding supply of instrumentation materials.

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Superconducting Supercollider (SSC), Waxahachie, TX

Description of Project

An overview of the SSC project is given in Part 2.

Contract Method

Roy F. Cook

Part 2 describes the SSC geotechnical monitoring programs that were based on bid specifications. However, as explained in Part 2, the first monitoring programs were of the professional services type. The sequence was:

- Professional services specifications for the exploratory shaft and first magnet delivery shaft.
- Bid specifications for two more magnet delivery shafts and one personnel shaft.
- Professional services specification for the two experimental halls

The circular exploratory shaft (ES) was the first underground excavation for the SSC project. It was more than 270 feet deep and was sunk through Austin Chalk and Eagle Ford Shale. It was constructed specifically to allow observations of subsurface behavior and determine in situ geotechnical parameters for design purposes. As a result, it was heavily instrumented. The first magnet delivery shaft (MDS N-15) was a production shaft. It was a large elliptical excavation (minimum dimension: 60 feet major axis; and, 30 feet minor axis) through chalk with a shaft station excavated in shale at a depth in excess of 200 feet. This was the second shaft to be constructed. It was instrumented to provide data for future designs but primarily to establish construction control during excavation of the shaft station.

The two experimental halls involved sufficient complexity to warrant monitoring programs directly controlled by the geotechnical design team. Our ability as designers, to rapidly react to changed conditions was of particular importance in the construction of these large halls that required excavations over 200 feet deep. The program monitored not only safety of working conditions during construction but also verified the stability of 150 feet high vertical walls in Taylor Marl and confirmed the performance of the system of tiebacks used to provide permanent support to these walls.

To initiate a professional services contract, we developed a request for proposals (RFP) that outlined the scope of work to be performed. For the early contracts, the proposals were elicited from a pre-selected group of established geotechnical firms; for the contract for the experimental halls, proposals were open to all. Award of the contract was a phased process. We first evaluated proposals from prospective professional geotechnical firms against a set of criteria defined in the request. The criteria covered such issues as the qualifications and experience of proposed staff, methods, quality assurance, and data presentation. The evaluation was performed by a panel consisting of personnel with technical and procurement expertise. We held interviews with the short listed candidates, and two senior staff proposed for the work were required to attend the interview. The interviews provided an opportunity for the proposers to explain their technical approach to the program. The panel selected a geotechnical professional firm based on technical merit. Once we had selected a prospective firm on its technical capabilities, we held separate negotiations on the cost proposal before final award of the contract took place.

The cost proposal was based on the minimum personnel requirements specified in the RFP and the proposer's estimate of the personnel he needed to perform the scope of work. During the negotiations, the work scope was further refined in order to meet the technical requirements of the program and to remain within budget constraints. Once the contract for professional services was in place, the geotechnical firm worked directly for PB/MK as an extension of the designer. Payment was on a time and materials basis. Since the professional services were separately contracted, their costs were itemized in the geotechnical budget. Costs were therefore subject to limitations set by the owner and were susceptible to cutbacks whenever budgets were constrained.

The prime contractor was required to provide various specified support services that were paid for on a unit price basis. For support services at the experimental halls that were measured by the hour, the basis for payment was identified in the specifications to be the PB/MK specified starts and stops that were consistent with the Contractor's established working hours. Payment for changes resulting from the monitoring program was handled by specifying that recommendations issued by PB/MK for any changes in construction procedures, materials or schedules were subject, where appropriate, to a change order.

With the exception of drilling services at the exploratory shaft and at the ground surface alongside the first magnet delivery shaft, instrument procurement and drilling services were not provided by the geotechnical firm. We placed contracts through the PB/MK procurement system for these services. This eliminated any requirements for the geotechnical firm to have in place a procurement system that met federal requirements and was approved as such by PB/MK. Procurement of instruments required the preparation of detailed materials specifications, including all installed components, readout equipment, tools and miscellaneous materials, factory calibration and quality assurance requirements, instruction manuals, and transit insurance. These details were required because the materials were to be handed over to the geotechnical firm for installation; hence they had to be as complete as possible. Requests for quotations (RFQ's) were issued only to suppliers of proven and appropriate products, and justification for these limitations were documented including some sole source justifications. The RFQ's required suppliers to respond with:

- Prices
- Delivery Information
- Warranty provisions
- Details of various specified components in cases where a complete descriptive specification was not possible, or where there were options
- List of tools for installation and maintenance
- Recommended spare parts
- Factory calibration procedures with traceability information
- Names of four previous users.

Selection of instrument materials was based on a low bid basis, but only after ensuring that all technical issues were satisfactory. A unit price payment schedule was used. Contracts for drilling services also required the preparation of detailed specifications. Selection was on a low bid basis, with a unit price payment schedule. Because there were three separate contract categories: geotechnical firm, materials and drilling services, PB/MK had a critical role in managing the program and coordinating site activities.

For the monitoring programs, we provided the direction for the programs. The geotechnical firms were responsible for:

- Calibrating all instrumentation
- Providing direction to drilling subcontractors
- Installing instrumentation at designated locations
- Assisting with the coordination of site activities
- Maintaining and repairing instruments
- Collecting, reducing and processing instrument data
- Interpreting and reporting instrument data.

Experience During Construction: Owner's Representative Roy F. Cook

Role of Author's Firm

The PB/MK Team prepared the geotechnical monitoring program and put together the RFP's and RFQ's. The instruments were procured by PB/MK to our specifications. We were also responsible for selecting the geotechnical firms to carry out the professional services contracts. The selection was based on technical merit. Once the professional services contract was in place, we played an active role in deciding the overall activity schedule and managing the contract. The field data were presented to us by the geotechnical firm and in collaboration with their engineers, we assessed the significance of the data. We used the data to make decisions on in situ geotechnical parameters and on the adequacy of installed support systems. Coordination of activities was perhaps the biggest challenge that we faced, involving potentially the geotechnical firm, a drilling subcontractor, the main tunnel contractor and subcontractors, the PB/MK construction management team, as well as ourselves!

Experience with Contractor's Liability/Responsibility

The professional services contractor was responsible for performing the specific tasks agreed upon with PB/MK in a professional and competent manner. This included installing and reading instruments, and interpreting and reporting the data. The geotechnical staff were responsible for assisting PB/MK with coordinating activities and providing advice on geotechnical conditions. However, the overall responsibility and liability for the use made of the geotechnical data for design, and decisions made on the performance of both temporary and permanent support systems lay with the PB/MK Team.

Experience with Contractor's Motivation and Quality

The geotechnical staff supplied to the project by the geotechnical firm were highly motivated. Since the services contract was on a time and materials basis, there was the opportunity to make sure that work was properly performed. This reflected in everyone's ability to produce quality work and make significant contributions to a unique and challenging project.

Experience with Payment Method

We paid for the time and materials used. This method of payment gave us the flexibility to readily adapt to changing circumstances. If additional readings were required, the reading schedule could easily be adjusted. The approach also accommodated additional geotechnical tasks. These required a proposal prepared by the contractor of the estimated costs for the new work scope. The estimate was then compared with an independent estimate prepared by PB/MK. Once agreement was reached between ourselves and the geotechnical firm on scope of work and the estimate of costs, the work could proceed.

There was the potential for cost escalation associated with the professional services type contract. If the prime contractor fell behind schedule, any additional time that the geotechnical firm spent on site was a reimbursable cost. Furthermore, there was no incentive for the prime contractor to accommodate the geotechnical activities since costs were borne by PB/MK. Although these factors were present, we do not believe that they significantly impacted our geotechnical program costs. We were able to control costs by the judicious management of the work scope.

Other Experiences During Construction

The SSC project was terminated before constructing the two experimental halls. However, the ES and MDS N-15 were finished and the professional services method for instrumentation produced quality work carried out within budget. We credit this to the effort that went in to the preparation of the RFPs for professional services and the detailed RFQs for materials, as well as to the professional approach adopted by the contractors, both the prime and the geotechnical firm.

The professional services contracts ensured that we, as the designers, had direct control over the quality of the work performed and was appropriate when the collection of geotechnical data for design or design verification was the primary objective of the monitoring program. Quality control was exercised through our selection of the geotechnical firms on the basis of their qualifications, experience and understanding of the requirements of the work. Once the programs were underway, this approach provided flexibility to respond to unusual events or unexpected conditions as they were encountered. The approach provided capability to document unexpected conditions as they were encountered. The data contributed to design optimization and construction safety. It assisted in refining the values for geotechnical design parameters, and provided early warning of potential instabilities during construction. The disadvantages of the professional services contracts included possible cost escalation; and, the susceptibility of the programs to cutbacks because of their visibility within the geotechnical department's budget.

Lessons Learned

The monitoring program must have full support of the client. Clients are only willing to pay for programs that provide tangible benefits. Therefore, it is imperative to demonstrate up front, how the geotechnical data from a monitoring program can save money or prevent accidents. The success of the program depends on establishing clearly defined goals that benefit the client and are agreed to by the client.

The effectiveness of the program depends on the people doing the work. Therefore it is important to select a motivated professional geotechnical firm. The RFP must clearly identify the work scope and the technical panel reviewing the proposals must have a clearly defined concept of the requirements. Measurable factors must apply for each criterion that the proposers must address. This makes for an objective assessment of each proposal. In addition, it is important that the proposers provide their own view of the work rather than simply to repeat the statements from the RFP. Once the program is let it is important that the program remains focused on its defined objectives. Information should only be gathered that reflect these objectives.

Experience During Construction, Robert A. Robinson

Role of Author's Firm

Shannon & Wilson, Inc. (S&W) was selected by The PB/MK Team, based on our qualifications, from a group of 7 firms, to provide instrumentation services for the Exploratory Shaft (ES). Qualification requirements included a minimum of 5 years instrumentation experience for the senior instrumentation specialist and 3 years for the assistant. Subsequent to our selection, we negotiated a time and expenses contract for the work. To reduce costs to the client, PB/MK supplied an engineer to assist us with implementation of the instrumentation program and provide direct liaison with PB/MK. Based on our successful performance on the ES, we were selected to provide instrumentation services for the much larger N-15 Magnet Delivery Shaft (MDS). At a later time we were also selected to provide instrumentation services for the yet larger experimental halls, but the project was terminated before work could start.

Over a period of 18 months, S&W:

- Consulted with The PB/MK Team in the selection of instrumentation materials.
- Performed pre-installation acceptance tests on incoming materials.
- Prepared written detailed installation, monitoring, data reduction and maintenance procedures for each instrument system.
- Performed instrument installation and monitoring with assistance from the prime contractor.
- Reduced and preliminarily analyzed data and submitted daily and weekly data reports for use by PB/MK and the prime contractor in evaluating design performance and construction behavior.
- Provided input to the design team on the adequacy and possible adjustments of excavation and ground support techniques, ground behavior, ground water inflows and other aspects of construction that impacted our interpretation of instrumentation data.
- Attended meetings to discuss shaft construction progress and behavior.

Experience with Contractors

S&W worked closely and continuously with the prime contractors at both shafts throughout construction. In addition to excavating and supporting the shafts, the prime contractors were required to provide the GIS with access to each instrument location, implement the drilling and grouting of boreholes from below ground surface in the MDS, provide services such as welding, compressed air, water and electrical, and provide office facilities. Overall, the working relationship with the prime contractors was satisfactory. Conflicts with regards to installation and monitoring schedules were generally easily resolved with the intervention of PB/MK. The only real conflicts revolved around the measurement for payment of standby and support time during instrument installations and monitoring.

Liability/Responsibility

S&W was responsible for installing all instruments, including providing drilling services for all borehole instruments at the ES and for all instruments installed from ground surface at the N-15 MDS. S&W also provided most of the miscellaneous installation tools and materials, manhole covers, computer systems, and general software for processing data.

Since our client specified the instrument hardware, quantities and layout (with our input) we had minor financial liability for the possible failure of the off-the-shelf and generally reliable instrumentation systems, provided that they were installed in a responsible manner. Furthermore, since we were retained on a not to exceed, time and expense basis, we had little or no liability in terms of potential losses from changes in the construction contractor's schedule.

The nature of the instrumentation contract required the selection of a company with a qualified, reliable, flexible staff that was capable of overcoming most problems in the field and was willing to adjust working hours on an as needed basis to accommodate construction needs. There was also a responsibility to work well with the prime contractor, to gain his cooperation and impact his schedule minimally, while still completing the installations and getting the required data.

Motivation and Quality

The instrumentation systems had an over 95 percent survival and success rate. The high success rate and quality of this program is directly linked to the degree of experience and dedication of the field staff, coupled with the preparation of detailed installation procedures, and careful selection of instrument systems. The staff experience levels were in-part dictated by the RFP experience requirements and by the RFP selection procedure. Furthermore, because the instrumentation specialist was brought in as part of the design/construction management team, we were retained on a professional level, in contrast to having been retained as a subcontractor to the prime contractor. Consequently, there was considerable interaction with PB/MK and thus greater dedication to the overall needs of the project, and greater motivation to serve the needs of the designer. Overall this working arrangement, in our opinion, provided a much higher quality instrumentation project than had the same services been procured on a low-bid basis through the prime contractor.

A second source of motivation was the desire to obtain repeat business with a nationally recognized client. Thus every effort was made at performing a quality instrumentation program at the least possible cost to the client. This kind of incentive would not have been as significant had we been retained as a subcontractor to the prime contractor.

Experience with Payment Method

The instrumentation program was reimbursed on the basis of a "not to exceed" contract that paid on the basis hourly rates and marked up expenses. Therefore, it was relatively easy to adjust work hours based on changes in the contractor's advance rates, adjustments in construction procedures and behavior of the ground. This was a much fairer method of reimbursement than paying on an "as per instrument installed" basis, since we had little or no control over construction advance rates or ground behavior. While the ES contract length nearly doubled, total instrument program hourly costs increased by less than 50 percent, attesting to the efficiency of the instrument team, and the flexibility permitted by the "cost plus" contract approach. However, to satisfy the needs of the client, the hourly method required good daily logs of work accomplished, delays, etc. to establish that the GIS was working as cost-effectively as possible.

Other Experience During Construction

The greatest conflicts on the project dealt with the adequate definition and measurement for payment of delay or interruption of the construction contractor's work while installing and monitoring instrumentation systems. Although a payment item had been defined for standby time there was considerable debate as to what constituted a construction delay, and what should signal the start and end of an interruption. The contract must carefully define the measure of Contractor "standby time" and the required support (welding, hole drilling, etc.) during this standby time as well as limitations on installation and monitoring relative to excavation advance. The construction contract should also define when standby time starts and stops and when it doesn't apply, i.e. if the contractor is doing productive work such as shotcreting or rock bolting then either the owner should not pay standby or should pay at some lesser rate.

Murphy's Law stating that "What can go wrong does go wrong" is particularly appropriate for underground construction and construction instrumentation. Therefore, plenty of paid standby time should be provided for in the contract.

Lessons Learned

Numerous lessons can be learned from our experience in working for the owner's representative versus working for the prime contractor. These include:

- Working for the owner's representative provides the most flexible means for the instrumentation specialist to implement a major instrumentation program that can accommodate changes in construction schedule and program content as the work progresses.
- Having the client's engineer working with our staff provided excellent coordination with the owner's representative, and facilitated the resolution of many conflicts with the prime contractor.
- Preparation of detailed installation and monitoring procedures prior to installation, while time consuming and costly, provides an excellent QA document. These procedures minimized delays due to incomplete installation procedures or the absence of a necessary tool during installation, and improved planning and coordination with the prime contractor.
- The over 95% survival rate of instrumentation can be directly related to the well thought-out installation program implemented by experienced instrumentation staff.
- The greatest conflict between an instrumentation specialist hired by the owner's representative and the prime contractor is likely to center around the required support services, and the definition for payment of standby or delay time associated with instrument installations and monitoring.
- The instrumentation data generally benefits the designer and construction manager, rather than the prime contractor. Therefore, the implementation and modification of an instrumentation program should be under the direct control of the owner's representative, rather than under the prime contractor.
- The owner's representative has the authority and leverage to control the installation and monitoring schedule and obtain needed support from the prime contractor.
- When instrumentation specialists work for the owner's representative they are able to augment the construction managers' staff in recognizing construction problems and adverse ground behavior.

Rapid Transit Expansion Program (RTEP), Toronto, Ontario

J. Nick Shirlaw

Description of Project

The Rapid Transit Expansion Program (RTEP) of the Toronto Transit Commission (TTC) includes four new subway routes, two light rail routes and related yard expansions. Of the planned program, two subway routes and a yard expansion have now received both environmental approval and the necessary funding approvals. Final design of this initial portion of the program is currently in progress, and it is intended to let the first construction contracts in the middle of 1994.

The two sections of subway line currently under design are the Eglinton West subway line and the Sheppard subway line. The Eglinton West line consists of 4.7 route kilometres, and five underground stations. The Sheppard line consists of 6.4 route kilometres and five underground stations.

Both subway alignments follow major urban road corridors. The majority of the route is to be constructed directly under the road right-of-way.

Approximately 30% of the total route length will be constructed by cut-and-cover, typically where stations, crossovers and tailtracks are required. The remainder of the route will be constructed by bored tunnelling. The stations will generally have a centre platform configuration, and this configuration results in a tunnel spacing of 13.59m (centre to centre). The separation of the tunnels results in them occupying virtually the whole road reserve, and both the tunnelling and the cut-and-cover work will have to be performed in close proximity to buildings. Station excavations will typically be between 10m and 20m in depth.

All of the excavation for the two approved subway routes will be in soil; the rock is typically between 10m and 70m below the planned alignments. The soils comprise mainly hard or very dense glacial deposits. In very simplified terms, the soil consists of alternating layers of till, and the more granular interstadial deposits.

The topography of the area consists of a relatively flat plain, sharply incised by rivers, which typically flow in a south-easterly direction towards Lake Ontario. The tunnels for both subway projects will be driven from sites within river valleys to stations in the higher tableland. The majority of the tunnelling will be carried out below the water table. Groundwater conditions are complex, as the successive layers of till and interstadial deposits act as aquitards and aquifers respectively. It is not unusual to have two or three main groundwater levels in an area, and artesian pressures are common in or close to the river valleys.

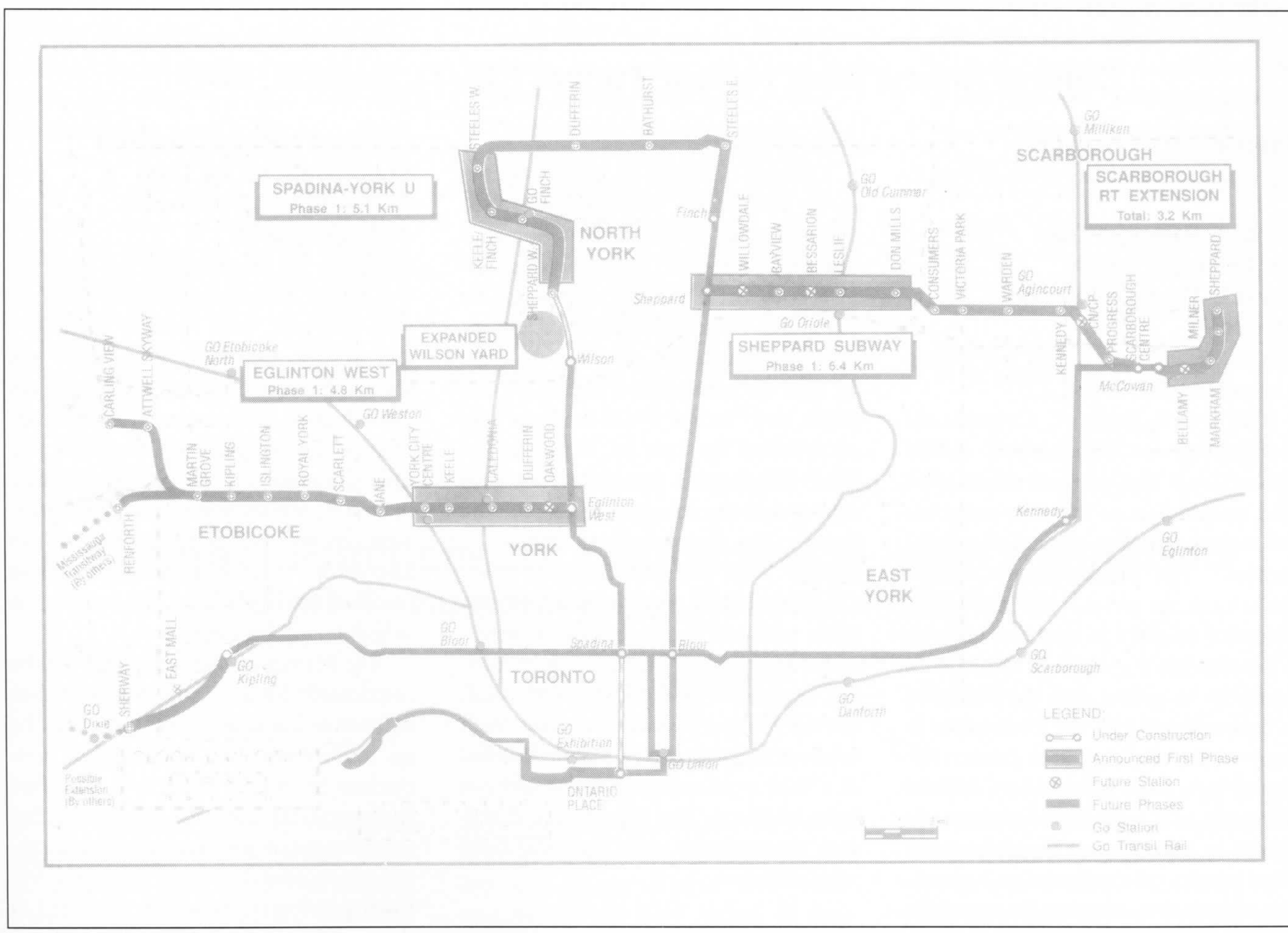
Except in the base of the river valleys, the soils are generally hard or very dense. Cut-and-cover excavations are expected to be supported mainly by soldier piles with lagging, except in a few areas where contiguous caissons will be used due to adverse ground or groundwater conditions, or to control building movement. The running tunnels will be driven by earth pressure balance shields, and lined with a segmental concrete lining.

For design purposes each subway alignment has been divided into six or seven sections. A section designer is appointed for each section; to date three section designers have been appointed for each of the subway routes, and one for a yard expansion. Each section will be divided into one to three construction contracts. The design is carried out to standards developed by the RTEP program managers, Delcan-Hatch joint venture. The program managers also review and coordinate during the design phase.

The general layout of monitoring instruments is prepared by the section designers, to a general standard developed by the program managers with assistance from the Program Geotechnical Consultant (Golder Associates). The section designers also specify an initial reading frequency and a review value for each instrument.

The majority of the instruments are being installed to monitor the contractors compliance with performance criteria contained within the contract specifications, and the effect of construction on adjacent structures. The most commonly specified instruments are:

- Building and utility settlement points - to measure the settlement of adjacent properties and utilities
- Piezometers - to monitor the contractors compliance with the dewatering specifications
- Inclinometers - to monitor compliance with performance specifications for retaining systems designed by the contractor
- Surface and subsurface settlement points - to measure general ground movements, and monitor compliance with performance specifications for movement on tunnelled sections
- Strain gauges on struts - to provide



Rapid Transit Expansion Program

information for the design of future excavations
- Convergence gauges on tunnel linings - to verify the design and performance of the lining

Contract Method

The primary purpose of the monitoring program specified by the TTC is to check the contractor's compliance with performance specifications with respect to controlling groundwater and ground movements. It is therefore considered that the monitoring forms part of the owner's inspection of the performance of the work, rather than being an integral part of the construction work. On this basis, and to ensure timely acquisition of data, the majority of the specified monitoring program is to be carried out by specialists retained directly by the TTC.

The contractors are being required to be involved in the monitoring process. This specified involvement includes:

- The installation and reading of any additional monitoring the contractor considers necessary to ensure the safety of the works
- The receipt and interpretation of monitoring data obtained by the monitoring specialists. This interpretation is for the contractor's own assessment of any necessary response; a separate assessment will be made by the TTC staff.
- Provision of support to the monitoring specialists with respect to drilling and grouting of holes
- Taking of additional readings, where this is considered necessary by the contractor
- Installing and reading strut monitoring and convergence gauges.

The supply of specialist geotechnical instrumentation will be through the specialists. These instruments will be generally be installed and read by the specialists, with the prime contractors providing any necessary drilling and other general support services. Exceptions to this general procedure are strain gauges on struts and convergence gauges in tunnels. These instruments are to be installed and read by the prime contractors. These instruments are specified to allow review of the pressure diagrams and lining design specified to the contractors, rather than to monitor compliance with the specifications. They will be placed within the excavations, and there is considered to be a significant risk of conflict between the owner and prime contractors if they were to be installed directly by the specialist consultant.

All monitoring data are to be stored in a data base, with one central data base for each subway route under construction. The chosen method of organizing the instrumentation places a considerable responsibility on the TTC and its consultants in timely acquisition and dissemination of data. It is intended to maximize the use of computers linked by modem to minimize the delay in onward transmission of data.

Central Artery/Third Harbor Tunnel (CA/T), Boston, MA

Description of Project

A project description is given in Part 2.

Contract Method: Dual Monitoring Program
David L. Druss and John Dunnicliff

The justification for a dual monitoring program is given in Part 2.

The Management Consultant (Bechtel/Parsons Brinckerhoff; B/PB) collects and reports instrumentation data, in addition to the data collected and reported by the construction contractors. The Management Consultant's task is primarily a quality assurance measure as well as a back-up to the contractor's work. It also creates flexibility to collect data supplemental to data collected by the contractor, in cases where readings at a greater frequency than those specified are deemed necessary, or if accuracy of contractor's data is in question, or to perform detailed studies of construction impacts. The minimum monitoring frequency for the Management Consultant's readings is approximately one reading per month per instrument.

Data are collected by B/PB from the same instruments furnished, installed and monitored by the construction contractors. Readout equipment is furnished to B/PB by the contractors as required. Upon completion of any instrument installation, readings are taken by both the construction contractor and B/PB, and "formal initial readings" are established for use by both parties. Once construction gets underway, both sets of data are compared on a periodic basis. The comparison of data on a regular basis has proven worthwhile. On several occasions, inconsistent data were obtained from the same instrument, indicating a malfunction of readout equipment or the instrument itself, or faulty data collection practices. Such malfunction may have gone undetected if a dual monitoring program had not been in effect. The opportunity to collect supplemental data has also been very useful.

Contract Method: Revised Specifications for Data Collection and Payment
John Dunnicliff

Although the dual monitoring program was planned as a complete and satisfactory program, with built-in flexibility and quality assurance, experience has shown that adequate data are not always provided by the construction contractors to the Management Consultant in a timely manner. Hence, on certain future contracts, revised data collection specifications will be used. Experience has also shown that the lump sum payment method is too inflexible, and a unit price schedule will be used.

The Management Consultant will be responsible for a greatly increased data collection frequency, and there will be no requirement for construction contractors to collect data at a specified frequency. Because the absence of this requirement raises concerns for contractor's accountability (see Part 2), the following two articles will be included in the specifications:

- The Contractor shall collect data

from instrumentation specified herein, in addition to the data collected by the Engineer, which the Contractor believes are required to ensure the safety of personnel and the Work, at no additional cost to the Department. Such data, together with data as specified in [article below], are referred to herein as Contractor's data. Such Contractor's data will be accepted by the Engineer only if the data are collected and plotted as specified herein, if readout unit materials and calibrations are as specified herein, and if submitted to the Engineer within one month of data collection.

- The Contractor shall install instrumentation, in addition to that specified herein, that the Contractor deems necessary to ensure the safety of personnel and the Work, at no addition cost to the Department. The Contractor shall notify the Engineer at least 24 hours prior to installing any such addition instrumentation. Data resulting from such instrumentation are referred to herein as Contractor's data, together with data specified in [article above]. Such Contractor's data will be accepted by the Engineer only if the data are obtained from instrumentation furnished, calibrated, tested, installed and maintained as specified herein, if the data are collected and plotted as specified herein, and if submitted to the Engineer within one month of data collection.

The following additional articles will be included:

- The Engineer will collect data, generally weekly but not less frequently than monthly.
- The Contractor shall satisfy itself on the validity of formal initial readings, and shall sign its agreement to such readings. No instrument will be accepted or paid for until formal initial readings are agreed upon as specified herein ["formal initial readings" are defined for each type of instrument].
- The Contractor shall provide and facilitate safe access to the Work at all times for the Engineer to collect data from specified instruments, and also from any additional instruments installed by the Contractor. Safe access shall include, but not be limited to, cessation of work activities, temporary relocation of obstructing materials and equipment, provision of ladders, working platforms and hoisting services, and any other needs that, in the opinion of the Engineer, are necessary to ensure the safety of data collection personnel.
- The Engineer will provide data to the Contractor. When data indicate that a change has occurred as specified in [article specifying hazard warning levels], the Engineer will notify the Contractor within 24 hours of collecting the data. These data will be preliminary data, and will be unchecked. The Engineer will provide formal data reports to the Contractor, generally within one week of collecting the data, for data that the Engineer anticipates are affected by construction activities.
- Each week the Contractor shall submit to the Engineer a description of the work performed during that week including [detailed listing of what is required].

The Specifications will also include detailed requirements for the Contractor's obligations relating to "Contractor's data", including data collection and reporting.

The unit price payment schedule will consist of:

- A series of bid items for furnishing each readout unit.
- A series of bid items for furnishing and installing each instrument type, measured either by the linear foot or by each instrument.
- A lump sum for "General Geotechnical Instrumentation Requirements," including protecting and maintaining all installed instruments, repairing or replacing damaged instruments, furnishing specified submittals, storing and disposing of instruments, providing safe access to instruments for data collection by the Engineer, accepting validity of formal initial readings and signing acceptance as specified, interpreting data, and all other items of work specified in this section for which no separate bid item is provided.

Contract Practices for Geotechnical Instrumentation
Part 4 - Summary and Recommendations

John Dunnicliff

Summary

When I look at a report or a technical paper, I first read the "Summary" or the "Conclusions", and then decide whether I want to read anything else. Often the answer is no. If I try to summarize the articles in this issue of GN I will, apart from having a hard task, do a disservice to the authors, because you may not read any more. There is a lot of "meat" in the articles, and the wide variety of decisions on contract practices results largely from a wide variety of circumstances. So that's my excuse for this non-summary: if you're interested in the subject, you should read it all, and make your own summary and conclusions, based on what you read and the reason for your interest.

Pointing Directions for the Future

I remain convinced that geotechnical instrumentation work should be considered a professional service, rather than as a low-bid construction item. I once heard Wally Baker say "The person with the greatest vested interest in the quality of the data should be given direct line responsibility for producing the data accurately", and to me this "says it all."

In my view, the following are some key points:

- Use professional service specifications whenever you can. They are the best way to ensure good motivation and quality.
- Be very careful with specification wording relating to the responsibilities of the prime contractors: there are some suggestions in the CA/T section in Part 3, headed "Contract Method: Revised Specifications for Data Collection and Payment".
- Avoid the use of lump sum payment methods, both for procurement of instrumentation mterials and for field instrumentation services.
- If you are forced to use a low-bid method, follow the goals given in Part I: clear, consistent, complete, correct, equitable. Specify stringent personnel experience criteria and submittal requirements, and the tasks listed in Table 6. If this results in a large number of specification pages, out of balance with the remainder of the specifications, so be it.
- Enforce the specifications fully.
- Give serious though to the use of the assigned supplier and assigned subcontractor methods. In my experience they work well. They are not used enough.

Future Contributions to Geotechnical News

The views of others are always welcome. Several people contributed drafts of sections for this series of articles, only to find later that the owner or client was not willing to allow publication. This was often because the contributors were negative about the contract practices adopted for a particular project. Despite this, GN and I will welcome any future contributions on this subject, either as discussions of these articles or as stand-alone contributions. Depending on the response to this suggestion, we can compile discussions as a future article, publish stand-alone articles, or include brief news items in Geotechnical Instrumentation News (see article in this issue).

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Load Cell Calibrations

Barrie Sellers

Introduction

Load cells used to measure loads during testing of tiebacks, driven piles and drilled shafts give calculated loads which are frequently in disagreement with loads calculated on the basis of hydraulic jack pressure and piston area. Because of this, there is a general lack of confidence in load cell data and the fault is often ascribed to manufacturing defects, or to improper, inaccurate calibration procedures. Nevertheless, it is also well-known that the effects of eccentric loading and uneven and/or warped bearing plates do have a profound effect on load cell readings. The purpose of this technical note is to provide some insight into these effects.

Load Cell Calibration Procedures

The usual calibration procedure is to use a testing machine to apply a load to a load cell. The measured load cell output is then correlated against the known applied load as measured by the testing machine. Usually, the testing machine has a hydraulic pressure applied to a piston of known cross section area. The testing machine itself is checked out periodically by running tests on a load cell traceable to NIST and there is generally little doubt about the accuracy of the testing machine. Accuracies of ¼% FS, ½ % FS or 1% FS are normal.

Usually, the calibration tests are performed between large, flat parallel platens in the testing machine so that there is no bending of the platens, only the elastic compression in the zone immediately bearing against the load cell.

Field Arrangements

Such a state of affairs may not exist on the job site since the bearing surfaces next to the load cell are usually much less rigid, and liable to bending.

This bending is particularly apparent if there is a mismatch in size between the load cell and the hydraulic jack. If the hydraulic jack is larger than the load cell there is a tendency for it to try to wrap the intervening bearing plate around the load cell. If the hydraulic jack is smaller than the load cell it will try to push the intervening bearing plate through the hole in the load cell.

Thicker bearing plates will bend less, but the effect will never be entirely eliminated. The consequence of this bending can be quite large since the effect on the load cell is to cause it to either barrel out at its mid-section if the jack is too small, or pinch in at its mid-section if the jack is too big. For electrical resistance strain gage load cells, the gages are usually located on the outer surface of the load bearing cylinder at its mid-section.

Report on Recent Testing

A series of tests were conducted in a testing machine to investigate the magnitude of this effect.

- An electrical resistance strain gage load cell with a bearing surface of 4" ID, 5¾" OD was used.
- Simulated jack A had a bearing surface of 2" ID, 4" OD.
- Simulated jack B had a bearing surface of 4" ID, 5¾" OD.
- Simulated jack C had a bearing surface of 6" ID, 8" OD.
- The maximum applied load was 150 ton.

From the results it can be seen that if the jack is smaller than the load cell, the load cell will over-register, while a jack bigger than the load cell will cause the load cell to under-register. The effect is bigger if the bearing plate between jack and load cell is thinner.

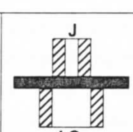
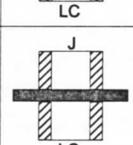
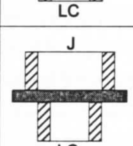
The correct bearing plate thickness will of course depend on the extent of the mismatch between jack and load cell. However as a rough rule of thumb the following thickness should be required:

75 ton capacity	1.5" thick
200 ton capacity	2.5" thick
350 ton capacity	3.0" thick

The plates should be ground smooth, flat and parallel.

Conclusion

The consequences of all this would seem to indicate that, for best results, the load cell calibration should be performed with the actual hydraulic jack that will be used, both being placed in the testing machine at the same time. Or failing that, the load cell should be loaded through a ring, having the same dimensions as the hydraulic jack bearing surface, positioned on the other side of a bearing plate of the correct thickness. In this way one of the variables affecting the agreement between load cell readings and hydraulic jack readings can be removed and the agreement

Jack		Load Cell response to applied load (100%)	
		1" thick plate	2" thick plate
A (smaller)		108%	102%
B (same size)		100%	100%
C (bigger)		96%	98%

should be that much closer.

This technical note has addressed only the subject of the size mismatch between load cells and hydraulic jacks. Other factors affecting the agreement between load cell readings and hydraulic jack load are important. For example, frictional losses within the hydraulic jack can cause under-registering of jack load indications by as much as 15%. (Dunnicliff 1988[1] Section 13.2.6)

Also, annular style load cells are susceptible to end effects and eccentrically applied loads. The height of the load cell should exceed 4 times the wall thickness of the annulus and at least 4 strain gages should be used (Dunnicliff 1988[1] Section 13.2.8) increasing to 8 or 12 in number as the size of the load cell increases.

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Advances in Slope-monitoring Instrumentation at Syncrude Canada Ltd.

Gord McKenna, Gord Livingstone, and Ted Lord

Introduction

Syncrude Canada Ltd. operates an open-pit Oil Sands mine near Fort McMurray, Alberta, Canada. The ore-body is composed of bituminous sands which contain numerous thin, overconsolidated, clay layers that can cause highwall instability. The ore is excavated by four large ($70m^3$) draglines which sit near the 45mhigh highwall and must be protected against being undermined by a highwall failure. The highest-risk highwall-failure mode is a blockslide which can occur along any Estuarine Clay layer that dips at an angle of more than 10 into the pit. A blockslide can occur after only 10 to 15mm displacement along a clay layer and moves at a critical velocity of about 1mm per hour just prior to failure. Other failure modes include ore-windrow-driven slides along flat-lying Marine Clay layers and flow failures of rich Oil Sand, which cause deep tension cracks and undermining of the dragline bench. Slope monitoring for Syncrude's recently opened truck-and-shovel Oil Sands mine is also required to protect mining equipment against a variety of slope-failure modes. Since mining started in the late 1970's, there have been about 40 blockslides, 300 windrow-driven slides, extensive flow failures, and a variety of other slope failures.

To ensure safe, reliable, and economical mining, Syncrude has an intensive highwall monitoring program that includes 24hour visual monitoring supplemented with geotechnical instrumentation. Approximately 80km of highwall are mined each year each of four draglines mines 10 panels that are 2000m long. About 20% of the highwall has significant potential for slope failure. Each year, between 300 and 800 slope inclinometers (SI's) are installed, monitored, and mined out one per dragline cut in problem areas to monitor slope movements around operating draglines. The monitoring program is continually reviewed as ground conditions change and as advances in instrumentation become available. In the last several years, there have been some major advances the most dramatic ones in the area of geotechnical instrumentation as described below.

Remote Slope Inclinometer (RSI)

The greatest improvement in geotechnical instrumentation was the development of the Remote Slope Inclinometer (RSI) (Figure 1). This system allows SI's positioned between the highwall and the dragline to be read while the dragline is operating. Previously, the dragline was shut down every one to two hours for eight to fifteen minutes for manual reading of the SI. This time delay resulted in up to 40 hours of downtime per month for some draglines.

The RSI is a robotic unit for reading SI's remotely. Each RSI unit consists of a Slope Indicator Company SI probe connected to a chain which is drawn up and down the slope-inclinometer-cased borehole by a motor/pulley drawworks. The system is housed with electronics in a steel box that can be moved by one person. The RSI is typically operated remotely from a pick-up truck positioned 20m away (or farther) or the RSI can be operated in a stand-alone mode with data being retrieved periodically. The system can be programmed to read the entire SI at any time interval, or to continuously monitor one or more movement depths, or combinations thereof. Overriding software automatically raises the SI probe to the top of the hole if reading difficulties are encountered.

The RSI operates in all weather and at outside air temperatures of 40 to +35C. Four units were constructed and are now part of the day-to-day monitoring program. However, mechanical problems with the chain have caused considerable downtime for the RSI units. The software and the mechanical drawworks are presently being upgraded and a preventive maintenance program has started. Even under present conditions, the RSI saves approximately 45 minutes of downtime per day for a dragline mining in a problem area. By operating the RSI remotely, the safety of the monitoring engineers is also increased because they are less exposed to operating mining equipment, unstable slopes, and adverse weather conditions.

(1) Dunnicliff, J., (1988), Geotechnical Instrumentation for Monitoring Field Performance, Wiley, 577 pp.

Slope Inclinometer Data Management System (SIDMS)

Parallel to the RSI development, PC-based software was developed for recording and virtually real-time presentation of SI data in the field. Each pick-up truck is equipped with a 386 computer and a dot-matrix printer. A 3.5inch diskette containing SI data is brought into the office at the end of each shift along with 8.5 x 11inch printouts of the data. The data files are uploaded from diskette into SIDMS, which is an OS/2-based computer program that is integrated with a SYBASE database. This LAN-based system allows the storage and presentation of current and historical SI data about 5000 SI's with an average of 11 reading sets each and is used by four engineers every day. Data between any two reading sets can be compared and presented in tabular and graphical form. Figure 2 shows four examples of standard output plots. Ad-hoc queries allow historical studies of SI data for particular areas, geological units, or highwall failure modes.

Syncrude has uses a new method of presenting SI data, similar to the presentation of geophysical dipmeter logs. The tadpole plots (Figure 2c) show the depth of the reading and the amount of total movement with the movement direction denoted by the tadpole-tail orientation the top of the page is north. Movement direction is thus displayed and both the Aaxis and Baxis movements are presented as a resultant vector. The movement direction can thus be immediately compared to the geological structures or the slope direction. With experience, failure-mode signatures can also be readily interpreted.

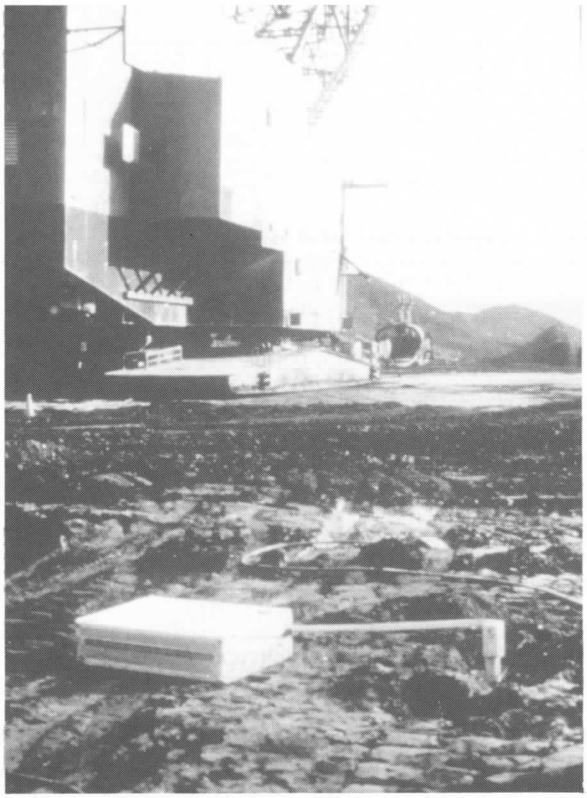

Figure 1. Syncrude Remote Slope Inclinometers (RSI's) are robotic devices that read slope inclinometers near operating draglines. The RSI's can be programmed to read the entire length of the slope inclinometer, to continuously monitor displacements along discrete planes, or combinations thereof. They may be used in stand-alone mode or operated remotely.

New SI reading methods

Because the failure planes along clay layers in the Oil Sands are less than a few millimetres thick, the 2foot (610mm) probe-wheel spacing spans the movement zone. To monitor the development of slide, Syncrude uses continuous monitoring to measure shear movements at discrete depths. An SI probe, left in place straddling the shear plane and read every 10 minutes, can accurately measure changes in displacement of 0.0001ft (0.03mm) over 10 minutes. This method allows accurate determination of velocities and accelerations of slides. Many of Syncrude's highwall monitoring criteria are based on displacements and velocities measured by SI's. Figure 2d shows a displacement-versus-time plot for a shear plane with continuous monitoring of velocities of up to 14mm per day over a short period. The relatively brittle nature of the Estuarine Clays and the low velocities that are observed just prior to failure of blockslides means that this high-degree of accuracy is required for effective monitoring.

SI's are normally read at 2foot (610mm) depth intervals, coincident with the wheel spacing of the SI probe. A series of tests to evaluate reading SI's at depth intervals that are shorter than the wheel-spacing were performed. Figure 3 shows 2foot readings, 1foot readings (305mm), and 2inch (50mm) readings. It was found that profiling at a 2inch (50mm) interval through a movement zone took only 20 minutes and with arithmetic manipulation in a spreadsheet, provided virtually the exact shape of the SI casing (Figure 3). However, due to stiffness and strength differences between the ground, the grout, and the SI casing, a distinct shear plane caused the SI to deform over a 500mm to 1000mm zone. Although the shorter reading interval provides additional data, it is usually not useful. The increased accuracy in determining the failure depth was tempered with the inaccuracies in geological coring and surveying and it was found that with these limitations, that readings at smaller intervals than the 2-foot wheel spacing are not worthwhile for current monitoring at Syncrude.

Six-inch diameter SI casing

Many of Syncrude's movements along flat-lying clay layers are large enough to pinch off slope SI's without causing a highwall failure. Syncrude has investigated development of sixinch (152mm) diameter SI casing as a replacement to the typical 3.34inch (85mm) diameter casing with Slope Indicator Company.

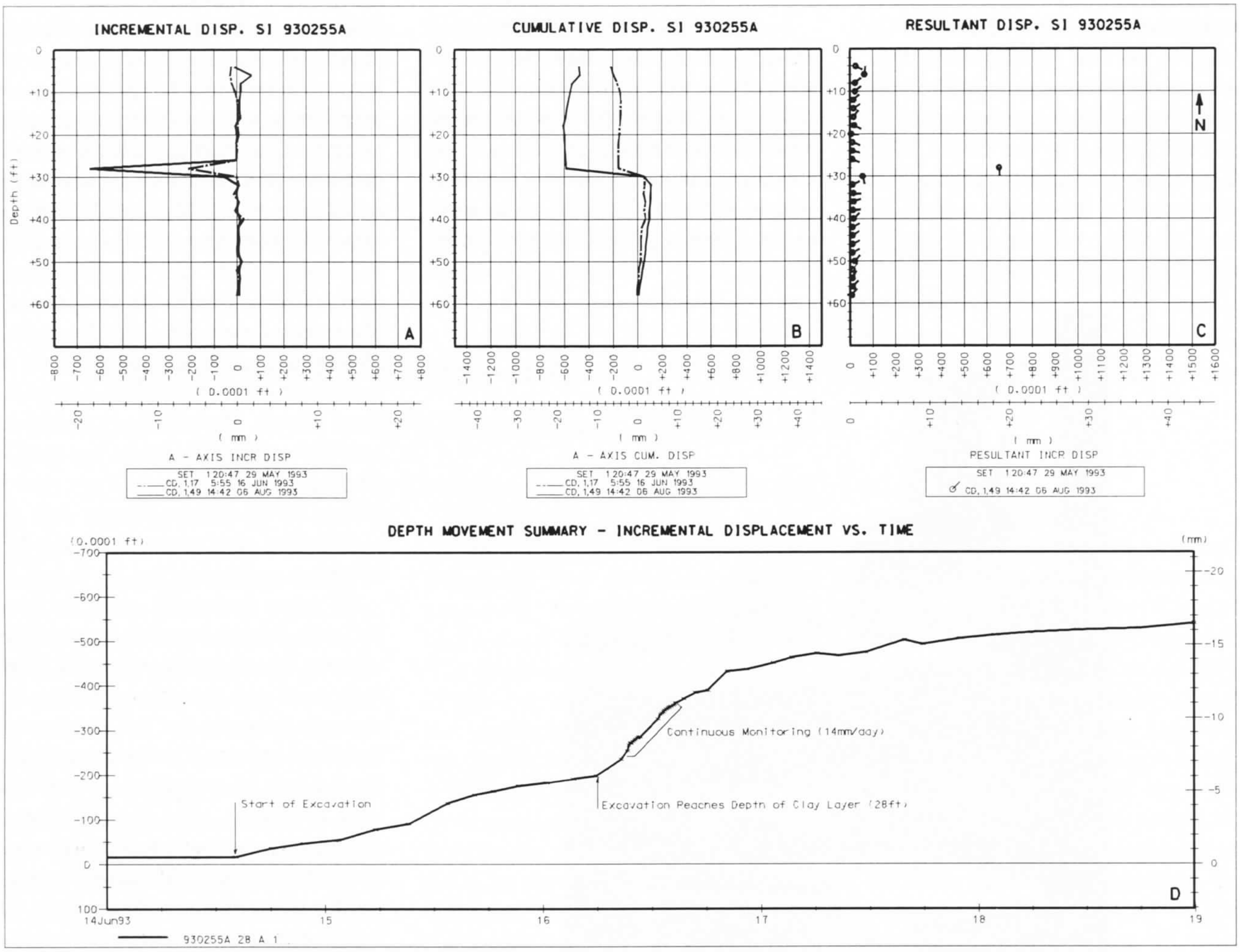

Figure 2. Example of output from Syncrude's Slope Inclinometer Data Management System (SIDMS). The plots show southward movement along a discrete shear plane at 28ft (8.5m) depth due to nearby excavation. Incremental, cumulative, tadpole, and continuous monitoring plots are shown.

Existing SI probes could be fitted with new wheel assemblies to read this larger-diameter casing. Whereas the existing casing pinches at about 50mm displacement movement along a distinct shear plane, this sixinch casing would likely accommodate two or three times as much displacement which would allow longer monitoring of movement zones and save on redrilling for pinched SI's. Development and field testing costs for sixinch diameter casing were significant at the time and while under consideration, alternative methods for monitoring were developed. Six-inch diameter casing remains a potential future enhancement to accommodate larger displacements.

To prevent casing pinching, some practitioners install heavy-gauge steel pipe around the SI casing through the shear plane and measure the overall deflection through the resulting movement zone. At the Syncrude mine, most of the large movement depths are shallow and so overcoring and large test-pits around the SI to the depth of a potential shear plane are used instead. The effect is to introduce a sand backfill zone between the sliding clay layers and the SI casing. Aside from any compressibility of the sand backfill, the entire movement is still recorded by the SI but spread out over a longer length of casing which reduces the potential for pinching. It also allows the SI to be used to measure shear planes below the disturbed zone with less chance of being pinched off at higher elevations.

Robotic optical survey system (ROSS)

To measure larger slope movements, Syncrude has developed a Robotic Optical Survey System (ROSS) which is composed of a commercially available, robotic theodolite and customized software. The ROSS uses an infrared beam to track target prisms near the highwall crest and provides realtime surficial monitoring of slope displacements. The information is sent by telemetry (available now as offtheshelf technology) to a computer aboard the dragline where it can be monitored. Flexible, userdefined alarms warn the monitoring engineer or dragline operator of critical ground displacements and velocities. The accuracy of Syncrude's system is 3mm for distance and 1 second for horizontal and vertical angles when used over distances between 900 and 1400m. It shoots and records 60 shots per hour and is typically set to track five to eight targets at a time when used to monitor slope

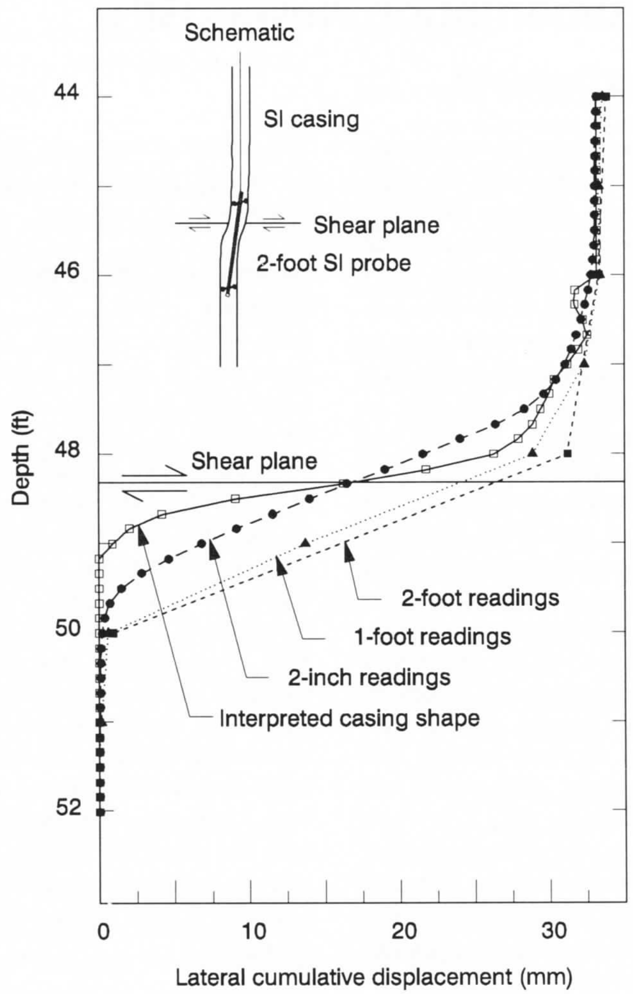

Figure 3. SI data from 2inch (50mm), 1foot (305mm), and the standard 2foot (610mm) reading intervals. The technique of taking readings at depth intervals of less than the 2foot SI-probe wheel spacing is easy but has limited usefulness.

movements near a dragline. The ROSS is very reliable, capable of monitoring slopes through almost all atmospheric conditions, and has been in use at Syncrude for several years.

Time Domain Reflectometry (TDR) research with fibre-optic and coaxial cable

In contrast to the normal SI's, Syncrude has also investigated a low-cost, expendable, down-hole movement monitoring system. Time Domain Reflectometry (TDR) techniques involve either a fibre-optic or coaxial cable grouted in a borehole and monitored to determine the location of deformation in the cable caused by slope movement. The technology is routinely used to determine the location of breaks or strains in the cable by telecommunications companies and utilities.

Through laboratory and field experiments, it was found that the system while good at indicating a movement zone, was difficult to calibrate to shear movements. Also, the direction of movement could not be determined. TDR is an emerging technology with a great deal of potential but its current limitations make it technically unsuitable as a highwall monitoring sensor. One potential application for the existing technology is a warning system where a coaxial cable would be grouted in a hole along-side an SI and would trigger an alarm immediately if a certain displacement or velocity is reached and thus allow timely reading of the SI.

Global Positioning System (GPS)

Syncrude monitors one of its major earth-fills using global positioning system (GPS) technology with accuracies better than 10mm (for both horizontal and vertical movements). Each monitoring station requires about 30 minutes of data collection and extensive data processing to achieve this accuracy. Syncrude will continue to watch the development of this technology for potential application for real-time slope monitoring.

Piezometers and SI's in the same borehole

Syncrude grouts piezometer tips in the same boreholes as SI's. A pneumatic or vibrating wire piezometer tip placed in a sand-filled slotted casing is taped to the outside of the SI casing during installation. Cement-bentonite grout is pumped from the bottom of the borehole, flooding the entire hole and surrounding the piezometer tip. Due to the very small groundwater equalization volumes for diaphragm-type piezometer tips, the grouted in piezometer functions as well as one installed with a sand zone and bentonite seals in its own borehole. This grouted-in installation method saves drilling additional boreholes, greatly reduces installation time, increases the success rate of piezometer installations, and provides piezometer data for only the cost of the tip and the leads. Accurate readings are assured for most soils, provided simple guidelines are met. Grouting-in piezometers has become the standard installation method for piezometers in the mine, even in boreholes without SI's.

Closing

Syncrude's draglines are a key component in the production of Synthetic Crude Oil which makes up approximately 12% of Canada's petroleum production. Monitoring of slope movements is essential for the on-going mining of Oil Sands in a safe and reliable manner.

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Gord Livingstone, and Ted Lord, Geotechnical Engineers, Syncrude Canada Ltd

Geotechnical Instrumentation News (GIN)

John Dunnicliff

Introduction

This is the first episode in what may become an ongoing saga in Geotechnical News. Its purpose is to share useful (and perhaps sometimes more light-hearted and trivial) information relating to geotechnical instrumentation. Each part will be brief, and I intend to focus on performance of instruments. As a practitioner, I know how difficult it is to be confident that such-and-such an instrument will work well, and it seems to me that if we share performance information with each other, we will make this less difficult.

This is therefore not "my column," but "our column." Please let me have useful information, in the form "We're about to do...and will tell you how it worked out later," or "We've just learned...," or other material that you think will help others. If your material is other than brief, and I think it's worthwhile, I'll suggest that you flesh it out as a stand-alone article for this magazine. If your material is controversial, and in particular if you want to report on something with which an instrument manufacturer may disagree, I will contact all concerned and mediate as necessary. All references to manufacturers and others in this first episode have been approved by the people referred to.

Whether or not this idea stays alive will depend more on you (as Stephen King says: "constant reader") than me.

In-Place Inclinometer

Slope Indicator Company has developed an "EL sensor" (electrolytic sensor) system that can be installed in an inclinometer casing as an in-place inclinometer (red book[1] Section 12.9.3). The system can be used with a datalogger for automatic and remote monitoring. Two versions are available, one with an individual cable to each sensor, and one with a single cable running from sensor to sensor. Potential cost savings for data collection personnel are large. Both Florida and Alabama DOTs are about to use the instrument in horizontal load testing of deep foundations, and I hope they will be able to report on performance later. I also hope that some of you will come forward with longer-term performance data: this will help us evaluate applicability to landslide and other long-term monitoring. When used for long-term data, the issue of transducer stability will be questioned: remember that with a conventional inclinometer we're able to deal with this by using the "check-sum" procedure as a "health-check," but we can't reverse the in-place version 180° for each reading. When using the in-place version, we can (and should) obtain duplicate baseline data with a conventional inclinometer, and could obtain duplicate data at any later time by removing the in-place hardware temporarily. But this would be laborious, hence the interest in transducer stability. And what are the pros and cons of the two versions of cabling?

Seals for Piezometers

How many of you have gone home and shouted at your spouse after a day of trying to get compressed bentonite pellets to the bottom of a borehole, or after trying to mix cement/bentonite grouts to a creamy consistency? No more!

Instead of pellets use granular bentonite. They don't get sticky so quickly, hence bridging is less likely. Among commercial sources are:

- Enviroplug Medium, - *Wyo-Ben, Inc. P.O. Box 1979, Billings, MT 59103 (800) 548-7055*
- Holeplug, 3/8 in. Size - *Baroid Drilling Fluids, Inc. P.O. Box 1675, Houston, TX 77251 (713) 987-5067*

Instead of bentonite/cement grout, use Benseal/EZ-Mud Slurry, from Baroid, as above. Use 135 lbs of EZ-Mud per 100 gallons of water, not 150 lbs as in the Baroid product information. This sets up as a very soft clay.

Determining Stress in Tieback Tendons

Spot weldable vibrating wire strain gages can be used to monitor strain, hence stress, in the bond zone of threadbar tendons, during load tests to determine the pattern of load transfer. But until recently there has been no way to do the same thing with stranded cable tendons. Geokon has developed a vibrating wire "strand gage," 4410 Series, consisting of a v-w transducer in series with a coil spring, and two bolted clamps. I've used this on several projects, with reasonable but not perfect success. We've learned about the importance of cushioning around the clamps with a soft material, to isolate the gage from the grout, and Geokon's instruction manual for this should be followed carefully. Is there any more experience out there?

Ultra-Precise Probe Extensometer

If the need is for very precise deformation data, with measurement points at close spacing along a borehole, conventional probe extensometers are not precise enough, and MPBXs do not have enough anchors. This situation arose at the Superconducting Supercollider project, where we needed heave data above and below the bottom of an exploratory shaft in shale. The selected instrument was the Incremental Extensometer (INCREX)[2], manufactured by Interfels, and available in North America from Roctest. This is similar to the Telemac Extensofor (red book Section 12.5.6). The data were remarkably precise, typically ± 0.08 mm over the 1 m length of the probe, i.e. a strain of ± 80 microstrain[3] This high precision results, in

(1) <u>Geotechnical Instrumentation for Monitoring Field Performance</u>, (1988) Wiley, 577 pp.

(2) Interfels News, (1991), No. 4, April

(3) Robinson, R.A., M.S. Kucker, and R.P. Brouillette, (1993), "Construction Behavior of the First Underground Opening of the Superconducting Super Collider Project, " Proc. Conf. Rapid Excavation and Tunneling, Chapter 39, pp 607-629. Also personal communication with Mike Kucker, July 1994.

part, from the use of rods to suspend the probe, and the price paid for high precision includes a lot of time and some aching muscles.

Inclinometer/Probe Extensometer Combination

Others have combined these two instruments in a single borehole by sizing a magnet/reed switch probe extensometer (red book Section 12.5.7) to fit around inclinometer casing. They said it worked, so I tried it, many times on one project. Don't! The grout requirements are incompatible. The inclinometer casing requires a grout with some body to it, so that the casing moves laterally with the ground. The probe extensometer requires a very soft grout, so that the anchors are not grouted to the inclinometer casing. If you pick a grout to suit one component, the other component doesn't work. Put your hand in your pocket and drill separate boreholes!

New Magnet/Reed Switch Probe Extensometer

Magnet/reed switch probe extensometers were developed by the Building Research Establishment in England in about 1970, and have been available from English manufacturers since then. I've recently used these, and have experienced problems with springs that are too weak, pneumatic cutter spring release systems that test one's patience, and magnets that are also too weak. In response to these issues, Slope Indicator Company has developed a version that works well, with strong springs and magnets, and a simple mechanical pin spring release system. They call it a "magnetic extensometer."

Measuring Strain in Concrete

I become increasingly convinced that the best instrument for measuring strain in concrete is Geokon's "sister bar" (red book Fig. 13.29), provided the concrete is thicker than about 2 ft, hence in drilled shafts and slurry walls. If other manufacturers develop their own versions, make sure that they follow the "rules" given on page 326 of the red book. If you install them in slurry walls, install one or two horizontally, parallel to the wall alignment, to monitor extraneous strains caused by factors other than stress change.

Soft Cover Version of Red Book

A soft cover version is now available from Wiley, priced at $49.95 plus state sales tax and shipping, ISBN 0-471-00546-0. The hard cover version is out of print, but I have a few copies for sale at $65.00 if anyone wants one.

October 11, 1994, ASCE National Convention in Atlanta

There will be a session in the afternoon on geotechnical instrumentation, consisting entirely of a panel discussion. The discussion will focus on important issues relating to geotechnical instrumentation programs, including:

- The need, if any, for instrumentation.
- The purpose and scope of instrumentation programs.
- Who installs and monitors the instruments, and evaluates the collected data?
- How should the reduced data be used to benefit the project?
- Threshold limits: who establishes these and why?

Panelists will be **Bob Leary** of FHWA, **Mo Hosseni** of The George Hyman Construction Company, **Chuck Ladd** of MIT, **Steve Hunt** of STS Consultants Ltd., and myself. The moderator will be **Bryan Sweeney** of Haley & Aldrich, Inc. For more information, please contact *ASCE, or Bryan Sweeney at (617) 494-4910 x 420.* Note that ASCE's brochure describing the convention identifies the session incorrectly, on page 24, as a conventional "series of formal presentations" session. We thought that a discussion session had a good chance of being more meaningful.

Tests in Subway Tunnel

Plans are underway to construct a new tunnel very near to an existing subway tunnel. There are concerns about damage to the subway tunnel, hence a monitoring program is planned, primarily by installing instruments inside the existing tunnel. Because we don't know much about instrument performance in an active subway tunnel, with possible major influence of stray electrical currents, vibration effects and piston effects, the first step will be to install selected instruments as part of a "verification testing program." After this step is complete, the monitoring program itself will be planned. Instruments to be tested include:

- Vibrating wire strain gages, Geokon and Roctest.
- Vibrating wire jointmeters, Geokon and Soil Instruments Ltd.
- Tiltmeters with accelerometer transducers, Geokon and Slope Indicator Company.
- Tiltmeters with electrolytic level transducers, Applied Geomechanics, Inc. and Slope Indicator Company.
- Convergence gages, Roctest, Slope Indicator Company, and Soil Instruments Ltd.

We hope that all will work well, but we'll find out. Any bets? More later.

Walter Nold

Walter Nold developed the Nold DeAerator™ (red book pages 82, 83), initially in response to the need for high quality de-aired water in twin-tube hydraulic piezometers and liquid level settlement gages. Since then he has made, with his own perfectionist hands, 600 DeAerators. Users are geotechnical consulting firms (for field instrumentation and soil mechanics labs), university geotechnical departments, government agencies, the nuclear power industry and other industrial organizations, and medical organizations. It surprised and impressed me to find out that medical applications include non-surgical removal of tumors, prostate cancer treatment, cataract removal, and examinations with ultrasound equipment. An exciting example of an engineer moving beyond the limited field of engineering to help society in a broader way. For more information please contact Walter at 24 Birch Road, Natick, MA 01760, Tel. (508) 653-1635, fax (508) 653-5035.

Closure

Please take seriously my suggestion that by sharing information we'll help each other. Send me discussions of this first episode, new material, whatever you think may be useful, to *16 Whitridge Road, South Natick, MA 01760, Tel. (508) 655-1775, fax (508) 655-1840*