far safer and, incidentally, more reliable indication of developing defects than depending on the chance presence of a piezometer at a critical location.

Systematic measurements of the clarity of the seeping water, moreover, provide vital information that piezometers cannot supply. Indeed, walkover inspections by trained staff, on a systematic basis, often furnish the first and most significant indication of deterioration. They may even, under some circumstances, demonstrate the need for instrumentation to clarify understanding of a new development, but the instruments would then be located in strategic places, not on some routine geometric basis.

At the present mature state of earth-dam design and construction, it is unjustifiable to install instruments, which inevitably introduce anomalies into an embankment dam, for the vague purpose of advancing the state of the art. Only if there are specific questions, specific uncertainties about foundation or abutment behaviour, or specific geometries, materials, or foundation conditions that depart from precedent, can intrusive instrumentation now be considered essential or even desirable.

Monitoring of every dam is mandatory, because dams change with age and may develop defects. There is no substitute for systematic and intelligent surveillance. But monitoring and surveillance are not synonymous with instrumentation.

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Recommendations for Procurement of Geotechnical Instruments and Field Instrumentation Services

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It is axiomatic that those who have the greatest interest in reliable and high quality field data should have a major role in specifying the requirements and obtaining the data. Despite this, many contracts assign the responsibility for selecting geotechnical instruments and for field instrumentation services to people with fragmented roles and limited interest in the overall process. Two general categories for procurement of geotechnical instruments, and for the associated field instrumentation services are considered in this article: the lowest-price method and the professional service method. Pros and cons of both are discussed, and recommendations made for the use of the latter. The various tasks that relate to geotechnical instrumentation and monitoring are defined, and references are cited that give the views of others in the profession.

The authors hope that this article will be useful when trying to convince decision-makers to adopt professional service methods.

1. Purposes of Geotechnical Instrumentation and Monitoring

The term *geotechnical instrumentation and monitoring* will be used in this article to denote the entire process of planning and executing a monitoring program that uses geotechnical instrumentation.

Purposes of geotechnical instrumentation and monitoring include:

- Protection of third party property
- Control of the construction method
- Fact-finding in a crisis situation
- Providing legal protection
- Enhancing public relations
- Advancing the state-of-the-art

2. The Tasks

After the geotechnical instrumentation and monitoring program has been established by the project designers (including preparation of drawings, specifications and assignment of "response values" — those measured changes which will lead to the initiation of response actions), the various tasks that need to be assigned are shown in Table 1.

The eleven tasks in Table 1 represent the key links in a chain — any weakness or discontinuity will threaten the quality of information and increase risk. The importance of communication and co-operation among the participants in these tasks will be emphasised, and also that the responsibility for the tasks should be assigned to those who have the greatest interest in securing reliable and high quality data.

3. The Golden Rule for Assignment of Tasks

The golden rule for assignment of the tasks in Table 1 is:

> **To provide the best basis for securing reliable and high quality data, and hence for securing best value, the people who have the greatest interest in the answers to the questions should have a major role in obtaining the data.**

However, many contracts award geotechnical instrumentation and monitoring tasks on the basis of lowest price, and often also divide the responsibilities among several parties. At best this tends to create a major challenge in communication, but is more likely also to result in fragmentation and poor quality data.

4. Available Methods for Procurement

The following basic procurement methods are considered. The first two methods in each category can be considered as professional service methods.

4.1. Procurement of Geotechnical Instruments

(a) The people who have the greatest interest in the answers to the questions procure the instruments directly, making the selection on the basis of proven past performance, and negotiate prices with suppliers.

(b) The project designers enter an estimate of procurement cost in the construction contract bid schedule, and indicate that this is an "allowance item". The site supervision team (SST) in close coordination with the designers,

Table 1. Tasks That Need to be Assigned

Term Used in This Article	Task
Procurement of geotechnical instruments	Procure instrumentation hardware and software, and make factory calibrations
Field instrumentation services	Perform pre-installation acceptance tests on hardware and software
	Install instrumentation hardware and software
	Establish baseline readings
	Maintain and calibrate instrumentation hardware on a regular schedule
	Establish and update data collection schedule
	Collect data
	Process and present data
Interpretations and response actions	Interpret and report data
	Review need for response actions
	Implement necessary response actions

Table 2. Some Arguments for and against Professional Service Methods

Arguments Against	Counter-Arguments, For
The lowest-price method will give us the lowest price, which is what we want	What we need is reliable and high quality data, and we do not often get that when lowest-price methods are used. Lowest-price methods usually involve discontinuities in responsibilities and tasks, creating barriers to effective communication and teamwork
If geotechnical instrumentation and monitoring work is not performed by the construction contractor, responsibility and liability will be taken away from the construction contractor, thereby increasing responsibility and liability for the project designer	These concerns can be addressed through appropriate forms of contract, and by arrangements such as partnering
If field services are performed by the SST, this work may conflict with the work of the construction contractor, mutual scheduling will be a problem, and responsibility for damage will be unclear	These concerns can be resolved through a team approach backed by appropriate contractual clauses
We've always done it this way, therefore we're going to do it this way	This is not a helpful argument, because it doesn't acknowledge the need for reliable and high quality data. Construction contractors may see little or no direct benefit in the geotechnical instrumentation and monitoring, and may consider them a nuisance
We're required to do it this way	As immediately above
It is the sort of work that a technician can easily do	Yes, some of this work can be done by technicians, but a significant part cannot

Table 3. Example of Task Assignments. Amsterdam Metro North/Southline

Term Used in This Article	Task	Task Assignment
Procurement of geotechnical instruments	Procure instrumentation hardware and software, and make factory calibrations	Specialist instrumentation firm under contract to the owner [see 4.1(a) above]
Field instrumentation services	Perform pre-installation acceptance tests on hardware and software	Specialist instrumentation firm under contract to the owner [see 4.2(a) above]
	Install instrumentation hardware and software	
	Establish baseline readings	Data collected by specialist instrumentation firm under contract to the owner. Data evaluated by the owner and project designers. All parties, including the construction contractor, sign agreement to these readings before start of construction work
	Maintain and calibrate instrumentation hardware on a regular schedule	Specialist instrumentation firm under contract to the owner
	Establish and update data collection schedule	Data collection schedule, both for automatic and manual readings, is defined in the contract between the owner and the specialist instrumentation firm.
	Collect data	Data, both automatic and manual, collected by the specialist instrumentation firm, and transferred on line to the project designer, owner and construction contractor. Penalty clauses in the contract between the owner and specialist instrumentation firm for late presentation of data. Project designer has developed a database / visualisation system (GIS) for rapid processing and presentation of data on-line, which will also be used by the construction contractor
	Process and present data	
Interpretations and response actions	Interpret and report data	Interpretation by an "Engineering and Construct" (EC) team, consisting of owner, project designer and construction contractor, including if necessary the specialist instrumentation firm
	Review need for response actions	EC team, with appropriate contract clauses addressing the responsibilities
	Implement necessary response actions	Construction contractor

For further information about the monitoring system and strategy for the Amsterdam project, referece is made to Netzel and Kaalberg (2001).

subsequently selects appropriate instruments for the construction contractor to procure. Price is negotiated between the SST and suppliers of instruments, who then become "assigned suppliers". The construction contractor places orders on the instructions of the SST, pays suppliers' invoices, and is reimbursed at actual cost plus a handling fee.

(c) The instruments are procured on the basis of lowest price

4.2. *Procurement of Field Instrumentation Services*

If the construction contractor has a dominant interest, he will be typically responsible for all field services. Where the owner and project designers have the dominant interest, the following contract methods are considered:

(a) The SST performs field instrumentation services that require specialist instrumentation skills. If necessary, the owner or SST retains the services of a firm that specializes in instrumentation, using a professional service (time and materials) method for payment. Supporting work (that which does not require specialist instrumentation skills) is performed by the construction contractor.

(b) The project designers provide an estimate of the cost of specialist field instrumentation services, include it as an allowance item in the construction contract bid schedule, and indicate that this is an item for an "assigned subcontractor". The SST subsequently selects an appropriate specialist firm, using a professional service (time and materials) method for payment. If the construction contractor has had previous bad experience with the selected firm, he has the right to reject the firm as a subcontractor, and the SST then selects an alternative. The firm is employed by the construction contractor to perform field instrumentation work that requires specialist skill. The firm is paid by the construction contractor, who is reimbursed at actual cost plus a handling fee. The construction contractor performs supporting work.

(c) Field instrumentation services are undertaken either by the construction contractor or his subcontractor, on the basis of lowest price, usually by including them as line items in the bid schedule or as part of a lump-sum bid.

5. Discussion of Available Procurement Methods

If the geotechnical instrumentation and monitoring program has been initiated by the construction contractor, it is reasonable to assume that the construction contractor will select procurement methods that are most likely to secure reliable and high quality data. This particularly applies to applications of the observational method (Peck, 1969; Powderham, 1988) and to value engineering (Powderham and Rutty, 1994; ICE, 1996). It also applies to design/build contracts. The interest of the construction contractor in reliable and high quality data is usually very evident with these contractual arrangements.

The remainder of this discussion assumes that the geotechnical instrumentation and monitoring program has been initiated by the project designers in consultation with the owner, as this is the case for which the golden rule is often forgotten.

The four professional service methods above [4.1 (a), (b) and 4.2 (a), (b)] are much more likely to result in the goal of securing reliable and high quality data than the two lowest-price methods [4.1 (c) and 4.2 (c)].

When the 4.1 (a) and 4.2 (a) methods are used (geotechnical instrumentation and monitoring work not performed by the construction contractor), a concern is sometimes raised that responsibility has been taken away from the construction contractor, particularly in the event that instruments malfunction. In the experience of the authors this can be alleviated by appropriate specification wording, and the instruments are much more likely to work well if professional service methods are used.

When the 4.1 (b) and 4.2 (b) methods are used (assigned suppliers and assigned subcontractors) a concern sometimes centres on the efficiency of communication channels among the SST, the subcontractor and the construction contractor. In the experience of the authors, this has not been a problem in practice. Within an effective team environment such risks are minimized. There are benefits to using assigned suppliers and assigned subcontractors for geotechnical instrumentation and monitoring work, with allowance items in the bid schedule. These methods allow the SST to retain control over the selection of instruments and the personnel who will perform instrumentation field services. They also create flexibility to accommodate the changes that are inevitably required during construction. The cost is included in the construction budget — often a significant issue. It is important to note that the amounts for allowance items that are entered in the

Table 4. Example of Task Assignments. Multi-section Tunnel Project in North America

Term Used in This Article	Task	Task Assignment
Procurement of geotechnical instruments	Procure instrumentation hardware and software, and make factory calibrations	Specialist instrumentation firm under contract to the SST [see 4.1 (a) above]
Field instrumentation services	Perform pre-installation acceptance tests on hardware and software	Specialist instrumentation firm under contract to the SST [see 4.2 (a) above]
	Install instrumentation hardware and software	Specialist instrumentation work by firm under contract to the SST. Support work by construction contractor [see 4.2 (a) above]. In addition, construction contractor installs any additional instrumentation that he deems necessary to ensure the safety of the work
	Establish baseline readings	SST, together with construction contractor. Both sign agreement to these readings before start of construction work
	Maintain and calibrate instrumentation hardware on a regular schedule	SST. In addition, construction contractor performs these tasks for any additional instrumentation that he deems necessary to ensure the safety of the work. Construction contractor also collects data from instruments that have been installed by the specialist instrumentation firm, to the extent that he deems necessary to ensure the safety of the work
	Establish and update data collection schedule	
	Collect data	
	Process and present data	
Interpretations and response actions	Interpret and report data	SST in conjunction with project designer. Also construction contractor
	Review need for response actions	
	Implement necessary response actions	Construction contractor

bid schedule by the project designers should not be regarded as limiting, and the contract price should be increased by change order if needed.

Additional guidelines on use of professional service methods are given by Dunnicliff (1988, 1993).

Some of the arguments that the authors have heard against professional service methods are included in Table 2, together with the counter-arguments.

6. Examples of Task Assignments

Tables 3 and 4 gives examples of task assignments for two projects, and illustrate the adoption of professional service methods for geotechnical instrumentation and monitoring. The listed tasks are the same as those in Table 1.

7. Summary of Some Comments in the Literature

The quotations in Tables 5 and 6 refer to procurement methods and performance of geotechnical instrumentation and monitoring.

These quotations can be useful as precedents when trying to convince decision-makers to accept a professional service method. In the event that, despite strong attempts to convince them otherwise, they insist on using the lowest-price method, specifications for procurement of instruments and for field service must be clear, complete and correct. Guidelines on the content of such specifications are given by Dunnicliff (1988, 1993, 1999).

8. Summary

The authors strongly believe that geotechnical instrumentation and monitoring should be considered as a professional service, rather than a lowest-price construction item. Professional service methods within a team environment are the best way to ensure best value for the expenditure on instrumentation, an integrated win-win approach and good motivation, and therefore reliable and high quality data.

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Table 5. Comments Relating to Procurement of Geotechnical Instruments

Comment	Reference
The cheapest type of instrument to use is often the most expensive to buy, because reliability is essential and the cost of instrumentation is mainly in the installation, reading the instruments and analyzing those readings	ICOLD, 1996
A customer generally gets what he pays for. This practice [of low-bidding] also promotes use of marginal and inferior materials. A manufacturer's dilemma is created because there is little incentive to make product improvements and use higher quality materials that increase the product costs. Unless more informed buyers come forth and a change in the practices of low-bid procurement occurs, desirable advances in field instrumentation will be slow and unsatisfying	Mikkelsen, 1982
Cost ..should not be a deciding factor, however, because the total relative cost of instrumentation is too small to justify making economies in the overall project cost by choosing instruments of minimum cost	Sherard, 1981
The common *or acceptable equivalent* clause, combined with competitive bidding, leads inevitably to excessive emphasis on economy, with the result that high-quality instruments cannot compete. This keeps the quality of the average instrument on the market just above the *acceptable* level, a highly undesirable situation	Sherard, 1982

Table 6. Comments Relating to Procurement of Field Instrumentation Services

Comment	Reference
The following are generally not true when the contract for instrumentation is between the owner and the general contractor: (1) Contract is issued to entity most familiar with instrumentation. (2) Technical issues involving instrumentation system are resolved directly between owner and instrumentation specialists. (3) Staff is skilled in instrumentation issues. (4) Instrumentation issues are given top priority. (5) No additional markup on instrumentation system cost. All the above five factors are generally true when the contract for instrumentation is between the owner and an instrumentation company	ASCE, 2000
...it is important to select a motivated professional firm	Cook, 1994 (Superconducting Supercollider, Texas, USA)
The owner chose to use a [low] bid specification . .it would have been better to have most aspects of the instrumentation under the control of a single entity answering directly to the owner. .A switch to construction manager controlled monitoring was made after the experience and there was a marked upturn in the effectiveness of geotechnical instrumentation in the remainder of the tunnel system	Daugherty, 1994 (Multi-section tunnel project, USA)
The responsibility for the instrumentation should be in the hands of the party who needs the data the most, normally the owner's engineer or geotechnical engineer. Fragmentation of responsibilities frequently leads to problems… Geotechnical field instrumentation needs to be treated as a professional service with an accent on quality. Low-bid procurement of services and instruments almost always leads to low quality. This is in no one's best interests	Green, 2000
One procedure that is not recommended is for the instrumentation . .to be … billed in individual items for the main contractor to price	Kennard, 1973
Our experience with the [low-bid] arrangement is that regardless of the contract requirements, the quality and performance of the instrumentation program is often low on the list of contractor concerns. The natural result is that the quality of instrument installation suffers, readings are often missed, and reports are incomplete and/or late. The project owner agreed that the instrumentation installation, monitoring and reporting for this project should be performed as a professional service under the construction management contract	Klingler, 1997 (Downriver Regional Storage and Transport System, Michigan, USA)
It is . .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 [owner]	Shirlaw, 1994 (Rapid Transit Expansion Program, Toronto, Canada)
Despite being specified as his responsibility, a construction contractor typically will do all he can to minimise his effort with instrumentation work. In reality, the site supervision team will not stop construction because of this. Instrumentation work should be the responsibility of a professional organisation, with owner-control	Resident engineer, 2000. (Multi-section tunnel project, Hong Kong)
An informed choice of instruments, proper installation and a suitable monitoring regime are required to gain the maximum benefit from the financial commitment	Watts, 1999

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