A 13-Step Procedure for Systematic Planning of Monitoring Programmes using Geotechnical Instrumentation.

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Introduction

Planning a monitoring programme using geotechnical instrumentation should proceed through the steps outlined below. All of these planning steps should, if possible, be completed before geotechnical monitoring work commences in the field.

Step 1. Define the project conditions

The person responsible for planning a monitoring programme must become very familiar with the project type and layout, subsurface stratigraphy and engineering properties of subsurface materials, groundwater conditions, status of nearby structures or other facilities, environmental conditions, and the planned construction method.

Step 2. Predict mechanisms that control behaviour

Prior to developing a monitoring programme, one or more working hypotheses must be developed for mechanisms that are likely to control behaviour. In dam engineering, the term "Potential Failure Mode Analysis" (PFMA) is used, and this term could be used for other types of project.

Step 3. Define the geotechnical questions that need to be answered

Every instrument on a project should be selected and placed to assist in answering a specific question: if there is no question, there should be no instrumentation. This is the first golden rule.

Step 4. Identify, analyse, allocate and plan for control of risks

All risks associated with construction should be identified, and each 'geotechnical question' should be prioritised based on risk. Responsibility for each risk should be allocated to a single party or to more than one party. Risk responsibility allocation should be included in the construction contract documents.

Risk analysis embodies a wide range of scientific theories and engineering analyses to identify potential sources of risk, determine the probability of occurrence for each source, and estimate the consequences from each source of risk. Total risk is the summation of the probability of each source of risk occurring multiplied by the consequences of that occurrence. Risk can be decreased by actions that reduce the probability of a source of risk occurring or reduce the adverse consequences of that event occurring.

Step 5. Select the parameters to be monitored

Typical geotechnical parameters include:

- Pore water pressure in soil
- Joint water pressure in rock
- Displacement
- Total stress in soil
- Stress change in rock
- Load and strain in structural members
- Vibration
- Temperature.

The question "which parameters are most relevant?" should be answered.

Step 6. Predict magnitudes of change

Predictions are necessary so that required instrument ranges and accuracies can be selected. An estimate of the maximum possible value, or the maximum value of interest, leads to a selection of instrument range. An estimate of the minimum value of interest leads to a selection of instrument accuracy.

If measurements are for construction control or safety purposes, a predetermination should be made of numerical values that indicate the need for decisive mitigation measures. These values are often referred to as trigger levels (or hazard warning levels or response values). The concept of green, amber, and red trigger levels is useful:

- Green indicates that all is well
- Amber indicates the need for cautionary measures including an increase in monitoring frequency
- Red indicates the need for timely remedial actions and being prepared to implement them quickly.

Step 7. Devise remedial actions

Inherent in the use of instrumentation for construction purposes is the absolute necessity for deciding, in advance, a positive means for dealing with any problem that may be disclosed by the results of the observations. If the observations should demonstrate that remedial action is needed, that action must be based on appropriate, previously anticipated plans. Arrangements should be made to determine how all parties will be forewarned of the planned remedial actions.

Step 8. Assign tasks for the construction phase

The second golden rule (remember that the first golden rule has been given in Step 3 above) is: **Tasks should be assigned to the people who have the greatest motivation to achieve high quality data.** Many geotechnical monitoring programmes have been unsuccessful because planners of the programmes have assigned key tasks to people who have inadequate motivation. Hence this step is of the utmost importance, and is covered in some detail in this section.

The tasks include:

1. Selecting and buying instruments
2. Installing instruments
3. Collecting data
4. Maintaining instruments
5. Interpreting data
6. Implementing actions resulting from the data

and it is crucial to ensure that these tasks are assigned to the people who are most likely to maximize quality.

Clearly data interpretation (Task 5) should be the responsibility of the construction contractor, with input from the people who initiated the monitoring programme. Implementation (Task 6) should be by construction personnel.

Let's call Tasks 1-4 "Instrumentation field work". If principal construction contractors, temporary works contractors, specialist geotechnical subcontractors or design/build contractors have initiated the monitoring programme, clearly they have the greatest motivation, and these tasks should be assigned to them.

But if the monitoring programme has been initiated by the designer of the project, there are four reasons for not assigning instrumentation field work to the principal construction contractor:

A. Principal construction contractors may not have enough motivation to ensure quality. Use of the conventional lowest tender procedure, whereby these tasks are included as items in the principal construction contactor's contract, has often led to poor quality data
B. Monitoring cannot start until after award of the principal construction contract, hence adequate pre-construction (baseline) data are usually unavailable. Structures move and groundwater regimes often change from season to season, and geotechnical monitoring data cannot be interpreted correctly if baseline data are not established. Whenever practicable, it is very preferable to establish at least one year of baseline data
C. It costs the project owner more. Potential monitoring subcontractors give prices to principal construction contractors prior to tendering. After contract award, there is normally a bargaining process, and the project owner pays £1 for work that costs the principal contractor 85 or 90 pence
D. For multi-principal contract projects, there would be one monitoring subcontractor for each principal construction contract

However, if the monitoring programme has been initiated by the project designers and if local regulations demand that instrumentation field work must be assigned to the principal construction contractor, it is essential to have partnering and rigorous and **enforced** specifications.

If the monitoring programme has been initiated by the designer of the project, either of the following assignments are recommended for instrumentation field work:

- The owner's design or geotechnical consultant. In some countries this is not an option, because of concerns for liability and insurance cover.

- Specialist monitoring contractor under contract with the project owner, using a qualifications-based selection procedure, NOT a low bid.

Step 9. Select instruments

The preceding eight steps should be completed before instruments are selected. When selecting instruments, the overriding desirable feature is **reliability** and inherent in reliability is as simple as the requirements allow. Selection of instruments and readout equipment depends directly on the methods used for data collection. The scale of the geotechnical monitoring programme should match the scale and complexity of the geotechnical questions and should also match the identified risks.

Lowest cost of an instrument should never be allowed to dominate the selection. The least expensive instrument is not likely to result in minimizing project cost. In evaluating the economics of alternative instruments, the overall cost of procuring, calibration, installation, maintenance, monitoring, and data processing should be compared.

Step 10. Select instrument locations

A practical approach to selecting instrument locations entails three steps:

- First, establish the zones where risk is highest.

- Second, zones are identified, normally cross-sections, where predicted behaviour is considered representative of behaviour as a whole, these cross-sections are regarded as *primary instrumented sections*, and instruments are located to provide comprehensive information on ground/structural responses and construction performance.

- Third, because unknown factors may cause poorer performance at other locations, instrumentation should be installed at a number of *secondary instrumented sections,* to serve as indices of comparative behaviour. Instruments at these secondary sections should be as simple as the requirements allow and should also be installed at the primary sections so that comparisons can be made. If in fact the behaviour at a secondary section appears to be significantly different from the behaviour at the primary sections, additional instrumentation may be installed at the secondary section as construction progresses.

When selecting locations it should be recognized that some instruments will probably cease to function when data are still required, hence some duplication may be needed.

Some limited duplication of measurements leads to increased confidence in data, especially in areas of uncertainty or greatest change.

Step 11. Identify what issues may cause changes to the measured data

Measurements by themselves are rarely sufficient to provide useful conclusions. Geotechnical monitoring normally involves relating measurements to causes, and therefore records and diaries must be maintained of all factors that might cause changes in the measured parameters, including construction details and progress.

Step 12. Prepare budgets

Budgets should be prepared at this stage for all future monitoring tasks, including:

- Calibration
- Installation
- Maintenance
- Data collection
- Processing and presentation of monitoring data
- Interpretation of monitoring data
- Reporting of conclusions
- Implementation

It is then necessary to ensure that sufficient funds are-available. A frequent error in budget preparation is to underestimate the duration of the project and the total costs for data collection and interpretation. If insufficient funds are available, the monitoring programme may have to be curtailed or more funds obtained

Step 13. Prepare two sets of contract documents

First, for a contract between the owner and either the design or geotechnical consultant, or the specialist monitoring contractor. Remember to include risk responsibility allocation.

Second, for a contract between the owner and the construction contractor. This contract must include information about the first contract, because there needs to be interaction among all parties. Remember to include risk responsibility allocation.