MANAGING GEOTECHNICAL RISK

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What is geotechnical risk?
The saying "ignorance is bliss" applies well to geotechnical problems. Out of sight, out of mind often applies to ground engineering problems precisely because it is out of sight and often unknown or not well understood. However, sooner or later in a construction project, when some sort of geotechnical problem occurs, the "ignorance is bliss" approach comes back to bite hard.

Geotechnical risk is the risk to construction work created by the site ground conditions. It is a key element in any construction project which involves the ground (which is most of them), and particularly in the offshore industry where the consequences of installation difficulties or foundation failures can be enormous.

We have been involved in various projects where things have gone wrong due to geotechnical risk which has not been managed satisfactorily:

- A mat-supported jack-up experienced lateral (sliding) instability during a storm due to a thin layer of sand/silt which liquefied during the storm;
- A jack-up which experienced an uncontrolled punch-through of a thin stronger stratum and damaged a leg – requiring substantial repair work and long project delays;
- Unexpected project costs due to long delays during pipeline trenching because the full range of soil conditions actually present on the site had not been identified;
- Pile tip damage in seabed with varying bedrock elevation;
- Large volumes of grout needed for drilled and grouted piles in weak rock with voids.

The list could be extended. Geotechnical risks are as varied as the geologic conditions that create the hazard that is the source of the risk, and the types of construction. No construction project is risk free. Risk can be managed, minimised, shared, transferred or accepted. It cannot be ignored.

Strictly speaking, geotechnical risk is the combination of the chance or likelihood of an event occurring and the consequences of that event. Thus for example, high risk could be a result of a high probability of something occurring with a medium consequence (often cost). Geotechnical risk can also be understood in terms of the geotechnical hazard (e.g. liquefiable soil which is a source of risk) which is not related to the engineering design, and the vulnerability of a design to the hazard (i.e. the likelihood that a hazard such as liquefaction will produce unfavourable consequences with that particular design).
For example, a gravity-based structure is more vulnerable to liquefaction of a specific layer than a piled foundation which penetrates well below the liquefiable strata.

Ground-related problems adversely affect project costs, completion time, profitability, health and safety, quality and fitness for purpose, and can lead to environmental damage (Clayton, 2001).

One of the most common reasons for project overruns is the insufficiency of site investigation data. Figure 1 shows the results of a study which compared the cost of the site investigation work with the magnitude of the project overrun caused by geotechnical problems.

**Figure 1: Geotechnical construction risk mitigated by investment in site investigation**

This figure demonstrates that increased knowledge of the soil conditions leads to measures to deal with the soil conditions actually present (i.e. an appropriate design) and the consequent improved outcome of a project on time and budget. Risk is mitigated by data collection and good engineering design.

**Acceptable risk and consequences of failure**

All construction, and particularly geotechnical related components, involve risk. "Unforeseen ground conditions" is the knee-jerk reaction of a geotechnical contractor who encounters a problem. Unfortunately this may be a correct interpretation of events. But however detailed is the site investigation and survey, there always remains some risk.
An indication of acceptable risk is provided by Whitman (1984) as reproduced in Figure 2.

As discussed above, risk is measured in terms of the consequence of failure (e.g. cost in $) and likelihood (i.e. the annual probability of failure). One can see that there is a higher acceptance of risk for mobile drill rigs (e.g. jack ups) than for dams. Acceptable risk is related to the consequences of the event happening and is often project and client specific.

Figure 2: Risks for selected engineering projects


Geotechnical risk management
Geotechnical risk management makes good business sense. Uncertainties can be reduced or designed for, which may lead to reduced construction costs. Risk management may take different forms. Engaging a specialist geotechnical consultant whose role is to understand the geotechnical risks and develop a strategy for investigation and design is a simple approach. A more formal risk management
approach would include the specialist geotechnical consultant but would also define procedures and methods that have been developed in other industries. For example, the main steps could include:

- Identifying the geotechnical hazards that may be present at the site, and the risks posed to the foundation types, collating these in a risk register, and
- Assessing the vulnerability of the possible foundation types to the geotechnical hazards;
- Developing effective foundation solutions/designs to minimise the risk;
- Estimating time, cost and HSE impacts if the risks were to materialise;
- Evaluating the cost-effectiveness of further geotechnical investigation work to constrain the risks;
- Defining the minimum criteria for a ground investigation (geotechnical and geophysical).

As the project proceeds, the geotechnical consultant should update the hazard and vulnerability analysis as the design develops and further data is obtained.

The key to any geotechnical risk management are the specialist advisors. If they know their business, whether a formal risk management approach is adopted, or whether the geotechnical advisor simply does his job conscientiously and well using traditional methods, the geotechnical risk is likely to be well managed.

**Risk-adjusted project value**

How can the cost-effectiveness of further site investigation and survey work be determined? How much survey work needs to be performed and where is the level of diminishing returns? These questions often arise and Cathie (2000) has shown how it can be applied to geotechnical survey planning for submarine cable routes where burial of the cable is required by a plough or other equipment.

A consistent risk analysis approach which leads to optimum decision making involves calculating the risk-adjusted project value in monetary terms. What does this mean? If I own a house near a river where the flood risk is higher than average, I may be required by my insurance company to pay a higher insurance premium. The risk-adjusted value of my house is thus less than the value of a similar house which is not near a river because any owner must pay the additional insurance premium.

Risk adjusted valuation is applicable to many situations and can be used to optimise survey costs.

**Risk-adjusted project value applied to a subsea cable project**

A risk event is an event that leads to damage of the system. For the case of a buried cable, if it were by hit and damaged by fishing gear causing the line to fail there would be a cost to the operator of rerouting all the traffic. If the cost of rerouting the traffic (including some measure of impact on share prices) plus the cost of repair is equal to C ($) and the probability of occurrence of this event is P then:

\[
\text{Risk event cost (\$)} = P \times C
\]
There are many risk events arising from the various hazards to which a submarine cable is subjected (anchor, fishing, strumming, sediment movement, mudslide etc). If the probability of each event is assessed (say per 10km of the route) along with the cost (which may be a base cost plus a water depth related function) the cumulative risk event cost may be computed by summation.

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\text{Cumulative risk event cost ($)} = \sum \text{Risk event costs ($)}
\]

The cumulative risk event cost is effectively the cost that would have to be paid to an insurance company (excluding any markups) to cover for this risk. The project value must be reduced by this cumulative risk cost in order to compare project options with different reliabilities on the same basis.

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\text{Risk adjusted project value ($)} = \text{Project value ($)} - \text{Cumulative risk event cost ($)}
\]

These costs may be annualised by considering the lifetime of the project. The net present value (NPV) is also an indicator of the value of an investment (such as a site investigation) to a project and may also be used to the same end.

Generally the parameters such as project value and risk event cost are random variables so they are defined in terms of a probability distribution function. Figure 3 shows an example of such a distribution for two alternative project options. These could be thought of as two cable systems with different overall reliability levels i.e. different burial depths. Burial depth is investigated to determine the optimum burial depth (given that it cost more to bury deeper).

**Figure 3: Cost-risk evaluation using risk adjusted value or NPV**

![Probability distribution with two scenarios](image)
Scenario 1 is a low risk, low expected value project. It could represent a cable system installed with a demanding burial specification to reduce the risk event cost. However, the extra CAPEX that would be involved in mobilising high performance burial equipment would reduce the return on investment and, in the example, result in a reduction in the system value. The advantage of scenario 1 is that the probability of ever developing a negative value system is nil – a consideration that can have important financial consequences and may actually be the financial strategy required by the purchaser.

Scenario 2 is a more cavalier approach with a much wider probability distribution and a much higher probability of high value. On the other hand the risk of a negative system value is significant and may be unacceptable. This scenario could be developed using routing or burial specifications that offer a lower level of reliability.

Only two scenarios have been described above for simplicity. However, all decisions regarding potential risk reduction can be assessed according to their impact on the risk-adjusted value. Optimisation of the solution is the name of the game. The strategy and reliability level must be sought that optimises the parameters according to the purchaser’s requirements.

Risk-adjusted project value applied to other types of construction projects

A very similar approach can be used to determine how much money should be spent on a geotechnical investigation for any construction project. The key element that must be evaluated is the risk event cost for all risks. This could be a substantial task but can be performed at various levels. If the risks have been evaluated and a risk register established, the task involves assessing the probability of occurrence of each risk, and then potential consequence in monetary terms.

Consider a project which involves piling a jetty 1km long. The risks that might be considered could be evaluated for a specific design or various design options. They could include:

- Low resistance to driving leading to insufficient pile capacity
- High resistance to driving resulting in not reaching the target penetration
- High resistance to driving resulting in delays to the piling program and knock-on effect on other aspects of project schedule
- Buckling toe of pile or damaging the pile when driving into rock

In each case, a technical evaluation can be used to define a probability, or a probability distribution, for each event. The outcome may be very different along the length of the jetty so sections of say 100m may be assessed individually according to the soil conditions present.

Then the effect of gathering more information by performing extra investigation is introduced as another scenario. The risk event cost is re-evaluated using the new information available. Generally, the probability of an event occurring (e.g. pile refusal) will be much reduced because the soils are better characterised. Hence by studying the various options using the risk adjusted value, the optimum
amount of money to be spent on an investigation can be determined to maximise the project value overall.

**Utility of cost-risk modelling**

There are a number of important reasons why cost-risk modelling is useful:

1. Increased project/system value – For the example cable project, by correctly specifying the burial depth, the system value can be increased by 3 – 5%.
2. Favourable borrowing and insurance terms - The financial risk model which integrates the risks and risk mitigation measures is extremely useful for lending and insuring institutions to provide favourable terms.
3. A rationale is provided for selecting a particular strategy, foundation type, or spending money on further site investigation to reduce the uncertainties and narrow the risk-adjusted probability distribution.
4. All risks are integrated consistently: external hazard, geological hazard, financial risks, late delivery risks, permitting risks, market take-up, operation and maintenance costs/risks etc.
5. The Purchaser gets the best value project/system possible.

**Conclusions**

Geotechnical risk cannot be avoided. But it can be managed and mitigated. A good geotechnical consultant can greatly assist in this respect using either traditional "best practice" evaluations and advice or more formal geotechnical risk assessment. Spending money on geotechnical investigations and engineering is like a good insurance policy. It can save your project from serious delays and overruns provided it is taken out before the event.

**References**

