

Ground risk mitigation by better geotechnical design and construction management

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ABSTRACT: In 2006, the three international sister societies on geotechnical engineering, rock mechanics and engineering geology, respectively the ISSMGE, the ISRM, and the IAEG, formed the Joint Technical Committee (JTC4) on improving professional practice. Within JTC4, a number of working groups are focussing on specific topics. Task group TG3 is concerned with geotechnical risk management. The four authors are all members of TG3. Through this paper, being produced as part of their work, they aim to raise further attention about the needs for and benefits of geotechnical risk management in our professional practices.

Geotechnical “failures” during *construction* are here defined in the broadest sense to include a range of negative situations from collapses to major contractual claims. These failures may be the result of shortcomings in an earlier phase, geotechnical *design*, or from the application of poor procedures and control during *construction*. These areas will be explored in the paper with the aim of recognizing the importance of the implementation of both improved geotechnical risk reduction practices through *design* and improved control over risk during *construction* on site. These two aspects of risk mitigation are easily mixed, but have very different features, as will be explained.

Both strategies, geotechnical risk reduction and mitigation during design and geotechnical risk control during construction can be grouped under the same heading: geotechnical risk management. The importance of the geotechnical design process, the use of design codes, the evaluation of risk and the benefits of good risk management throughout the design and construction stages will be illustrated by means of case studies. A civil engineering approach will focus on risk reduction, while a mining engineering case study demonstrates how risk control may bring significant benefits, by optimizing value from mining while avoiding unexpected failures. For both cases a similar risk management approach is applicable. However, before any geo-professional can and should initiate a risk management process, there must be a degree of willingness to collect risks and to consider them independently, both individually and within the team. The level of understanding needed by the team is similar to that needed to operate the Observational Method. For this reason, the paper will first introduce the role of the people factor in risk management. The paper ends with some conclusions and recommendations, for improving ground risk mitigation by better geotechnical design and construction management.

1 INTRODUCTION

The establishment of this First International Symposium on Geotechnical Safety & Risk highlights two major issues. First, there is an obvious need for risk-driven geotechnical design and construction, for effectively responding to the globally increasing pressures of project complexity, and public demands on safety and sustainability in the context of severe (price) competition in many markets. Second, that this *first* international symposium on geotechnical safety and risk taking place in Shanghai, China, has not taken place until 2007. A remarkable fact, which indicates that the field of geotechnical safety and risk is still rather underdeveloped. In other words, it seems sadly to be almost an after-thought to our traditional approach for geotechnical design and construction. By comparison, the first international conference on soil mechanics took place in Harvard, Boston, in the United States in 1936, more than 70 years ago. It took 12 years before the second international symposium took place in Rotterdam, The Netherlands, in 1948 (Dunicliff and Peck Young, 2006). Given the rapid increase in interest in geotechnical risk management worldwide, it is expected that the Second International Symposium on Geotechnical Safety and Risk will occur more quickly than another 12 years.

This paper is concerned with project risk rather than the risk of health and safety of people - site workers and members of the public. Maintaining health and safety is of prime importance and must also be controlled. It is not addressed in this paper as the processes to control it usually relate to care in doing tasks and are essentially different in nature to the risks that cause project cost and programme over-runs (although there are often similarities in lack of control when things go wrong).

This sharp increase in geotechnical risk management interest is driven by the need to minimize *failures* and their associated costs, within the tight timeframes for project delivery subject to the quality and safety standards that are set for most major construction projects. As for instance highlighted by van Staveren and Chapman (2007), in particular in urban environments, poor or unknown ground conditions, vulnerable existing buildings and infrastructure and ever more stringent safety regulations make it quite a challenge to complete a project within the set budget and planning constraints. But also in more rural and remote areas, ground conditions can be very challenging and budgets and timeframes are often even tighter as the project is usually financially more marginal. With regard to allied industries that deal heavily in ground engineering, such as mining, similar business pressures rule their daily operations. Increasingly also, engineers are being asked to accept more risk, due principally to the proliferation of novel forms of contract. Often too, the level of remuneration may be tied to the level of risk that the engineer is prepared to take.

Geotechnical “failures” during *construction* are here defined in the broadest sense to include a range of negative situations from collapses to major contractual claims. These failures may be the result of shortcomings in an earlier project phase, geotechnical *design*, or from the application of poor procedures and control during *construction*. Failures may include lack of an adequate design process, over-reliance on codified design, poor conceptual understanding of the context of the ground conditions, poor construction management processes and poor control over quality (sometimes stimulated by excessive programme pressures). These areas will be explored in the paper with the aim of recognizing the importance of the implementation of both improved geotechnical risk mitigation practices through *design* and improved control over risk during *construction* on site. These two aspects of risk mitigation are easily mixed, but are not the same. In a construction environment, geotechnical risks are best mitigated by *reduction*, for instance by reducing the likelihood of a foundation collapse. In the mining environment it is usually uneconomic to minimize the probability of failure. However, mining failures must not be unexpected and therefore the risk associated with such failures *must be managed so that the consequences are not unsafe or economically devastating*. Therefore, while some failures during mining are desirable, otherwise much is probably being lost from following too conservative a process, the consequences of the failures must be carefully considered.

The financial impact of project failures is huge. In the Netherlands alone, failure figures are assessed between 5 % and 13 % of the yearly expenditure of the Dutch construction industry (for all failures, not just in the ground). While spending on construction totals some 70 billion euros per year (10th in the World for construction expenditure), between 3.5 and 9 billion euros are spent to respond to failures (van Staveren, 2006). With margins for construction firms typically

only between 2 % and 4 %, less than half the cost of failures, there appears to be a huge potential for financial improvement of the industry. Chapman and Marcetteau (2004) showed in the UK that about half of significant construction projects are delayed and of those, half of the delays are caused by problems in the ground. Applying this ratio to the overall construction failure rate would suggest an average of some 3 billion euros are due to ground-related causes in the Netherlands, or equal probably about 60 to 70 billion euros across the whole of the European Union (extrapolation based on the size of the Dutch GDP in 2006 at US\$613 billion to the whole of the European Union at US\$13,600 billion; CIA factbook, 2007).

Major causes of failure in the construction industry are unexpected ground conditions or ground behaviour. As for instance presented by Fookes et al (2000), numerous case histories over the last century illustrate that failing to effectively anticipate ground conditions is a main factor in construction problems. These ground-related problems *originate* often in an earlier phase than the phase in which they *occur*, as highlighted once again by Chowdury and Flentje (2007), based on the extensive work of Sowers (1993). By summarizing this latter study, in 57 % of the projects studied the later geotechnical problems *originated* in the design phase and in 38 % of the cases these problems *originated* in the construction phase. However, these geotechnical problems *occurred* in 41 % of the cases in the construction phase and in 57 % of the cases in the operational phase of the project. Apparently, both the design phase and the construction phase need careful consideration with regard to minimizing or even avoiding the *origin* of ground-related problems. For this reason this paper will focus on ground risk mitigation by better geotechnical *design* and *construction* management.

2 RISK, ITS MANAGEMENT AND PEOPLE

2.1 Risk and risk management

What is risk anyway? A generic definition of the term *risk* is the product of the *likelihood* of occurrence of an event and the *consequences* of that event. Normally these events are hazards, with the potential to have negative effects. In this paper risk is considered by definition as potentially harmful. *Risk management* can be defined as the overall application of policies, processes and practices dealing with risk (Clayton, 2001). Although a few very useful publications about ground risk management have become available recently, for instance the work of Clayton (2001), Hatem (1998) and van Staveren (2006), well-structured and explicit ground risk management is not yet common practice in the ground-related construction industry, nor yet sought by its clients.

2.2 The people factor

Before entering in more detail into the topics of ground-related risk mitigation during design and construction some attention should be paid to an often overlooked factor in the construction industry: the people factor. This is because people and organizational factors and not technological factors dominate as the cause in the majority geotechnical problems, such as foundation failures. Bea (2006) highlights the dominant role of the *people factor* in civil and geotechnical engineering failures, after studying more than 600 well-documented cases of failing civil engineering projects over almost 20 years. In some 80 % of the cases failure has been caused by what he terms extrinsic factors, such as human, organizational and knowledge uncertainties. The remaining 20 % involved (intrinsic) natural and model related uncertainties. These results align with similar findings by Sowers (1993). His study of more than 500 well documented foundation failures showed that 88 % of them were caused by human shortcomings. The remaining 12 % was caused by a lack of technology.

These facts demonstrate the need for greater attention to the role of individual professionals and their teams in geotechnical design and construction, as for instance advocated by van Staveren (2006) and van Staveren and Chapman (2007). Only after gaining awareness of the dominant role of the people factor in ground-related engineering and construction in general, and in its risk management in particular, specific competencies can and should be developed. An example is learning how to deal effectively with the inherent subjectivity of risk perceptions by individual professionals and their teams (van Staveren, 2006). In daily practice this proves to be a

real challenge for many engineers, who are clearly trained in dealing with engineering objectivity, rather than human subjectivity. Van Staveren (2007) and van Staveren and van der Meer (2007) present additional information about this topic, which is currently subject to ongoing research, development, education and training, both in the professional practice and at the civil engineering departments of Dutch technical universities.

2.3 Client education

The body that defines the overall process and sets the tone for subsequent relationships is the project developer or mine manager. If he chooses an adversarial approach, then most interactions on the project will be carried out in that mode. If he emphasises cost saving at the expense of risk reduction, then the design team may cut corners to please him, even though the end-result may be to increase his exposure to risks that he cannot afford. In some cases, the particular person may lack appropriate experience or be advised by overly adversarial lawyers who try to palm off all risk to others, even if the others cannot control the risks being passed. In these cases, the geo-professionals should advise (as far as they can) an approach that better protects the client's interests.

It is often the case that the client (the owner or mining company executive) does not understand the risks to which he or his company are exposed to on the project. In these situations, the client should specify up front the level of risk that he is prepared to accept, which could then become a design criterion. To do this, the client should concentrate on the desired outcome; it is helpful if this is agreed by others to be practically attainable. If his ability to tolerate a delay or cost-over run is low, then his procedures to manage risk should be robust, which will usually cost more to ensure a reliable solution. If his desire is for lowest cost, then the ensuing design is unlikely to give the most reliable outcome, so his chance of ending up disappointed is higher. A major initiative is needed to educate clients of what to tell his designers in terms of his priorities, recognising that he cannot have both least cost and most reliability. The client's decisions about procurement strategies and how he influences his designers have a large impact on how project risks are controlled.

At the end of the day, the client carries most of the project risk. Even under an adversarial contractual approach, he is unlikely to recover all his lost costs, especially consequential losses, which will be difficult to prove. So the best way to control significant risks is to reduce their likelihood and then to reduce the consequences of those that do come about, rather than invent new and onerous ways of shedding them to project partners. A prime aim of TG3 is to gather data to demonstrate these issues to clients.

2.4 Designer education

Sadly many failures are caused by a gap in the approach by professional people, sometimes by geotechnical engineers or other geo-professionals who should know better. Some geo-professionals (or their colleagues) accept or even seek out opportunities on projects for which they do not have sufficient skills – “I would love to do a 5 level basement, I have never done one of those before” or “this project will bring us into new areas of design” or “of course we can do one of those, even though our previous expert has now left us”. More problems are caused by geo-professionals accepting commissions at fee rates for which they cannot do a thorough enough job. Such fee competition where the scope of work is reduced below what is prudent creates a vicious circle, with other professionals having to respond in a like manner if they also want to win work. At the end of the day, such cycles only benefit the lawyers who are called in when luck runs out and the inevitable problems occur. There is no substitute for a thorough and systematic design process (for example Bieniawski, 1992; Stacey, 2006).

Generally our professional institutions have been cautious in censuring geo-professionals who lower professional standards below a prudent quality threshold, instead leaving them to suffer the commercial penalties of increasing professional indemnity premiums, or poor reputation. This may have to change in the future if we wish to raise designer standards.

Often too, the Designer will lack the requisite financial skills in order to make a full financial appraisal of a risk proposition, such as discounting cash flows, as part of a proper risk evaluation.

Engineers are often very cautious by nature for various reasons, and so innovation can be stifled and sometimes there is then a great reluctance to consider new techniques.

2.5 Constructor education

Many constructors now carry significant design responsibilities on projects and are not the “humble tradesmen” that they sometimes pretend to be. Most modern contractors are managed by qualified staff and have similar professional standards to designers. However, they are also subject to the commercial pressures of running a business, and may opt to price certain tenders more economically than they know to be sensible in order to win work. They may also price tenders wrongly because the information given to them is incomplete or is misleading about the complexity of the job that needs to be done – problems created for them by the designers and the client’s project managers.

For constructors, their situation is in some ways simpler than for designers. If they mismanage a project, they stand to lose more money than if they manage it well. However, if the project is going badly, under some forms of contract, they may believe that they stand to lose more by intervening helpfully than by ignoring the problems until they have unfolded. Under more modern forms of contract like “The Engineering and Construction Contract” (published by the Institution of Civil Engineers, 2000) and its “early warnings” ensures that problems are highlighted and dealt with at an early stage.

There are also situations where constructors also attempt projects for which they do not have appropriate personnel, experience or sometimes even equipment. In these circumstances the conclusion is often inevitable – the project ends up with significant delay while the problems are rectified – not what the client would have wished for.

3 GEOTECHNICAL RISK MANAGEMENT PROCESS

3.1 Brief introduction to GeoQ

In recent years, the attention to risk management processes has been growing in many areas of the construction industry. Guidelines appear, such as The Joint Code of Practice for Risk Management in the United Kingdom (British Tunnelling Society, 2003). In the Netherlands, a risk management approach for in particular ground-related design and construction has been in development at the National Institute for Geo-Engineering, GeoDelft, together with the industry, since 2001. This GeoQ approach, where Q stands for quality, is a cyclic risk management process for the ground in relation to construction activities (van Staveren, 2006). The main objective of GeoQ is to effectively manage the risky ground during all phases of a construction project, from the earliest feasibility phase right through to the operations and maintenance phase.

3.2 Risk management phases and steps

The GeoQ process is a formalisation of normal good geotechnical practice, emphasising the need for early data gathering. It is a framework for flexible risk management, with a number of risk management steps undertaken through the normal phases of a project, which should be taken sequentially. The position of the contracting phase is obviously dependant on the type of contract. Figure 1 shows a conventional contract, with the tendering stage between design and construction. The GeoQ process possesses the flexibility to position contracting also in between pre-design and design or even between feasibility and design, in case of a design and construct type of project.

According to the GeoQ process, in each phase six generic risk management *steps* have to be carried out, in order to implement proper ground-related risk management (van Staveren, 2006). These steps are presented in Figure 1.

A simplified example of applying the GeoQ steps, during a number of normal project stages, is shown in Table 1. For main project stages, such as design or construction, it is however highly recommended to carry out *all* six GeoQ steps. Obviously, the time and energy spend for each GeoQ step to take depend largely on the type of project phase and the project characteristics itself. But it is this cyclic repeating of risk management steps that will indicate any differences in the project’s risk profile and the required adoption of risk remediation measures. This major risk

management benefit is easily overlooked when only a single GeoQ step is performed in these project stages.

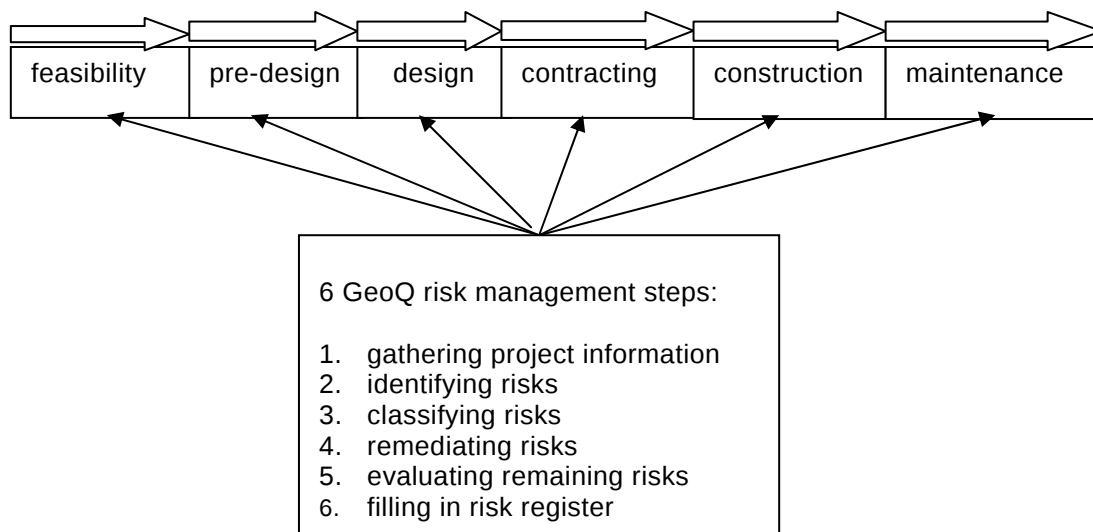


Fig.1 The GeoQ risk management model

Table 1 A simplified example of GeoQ steps during a few normal project stages

GeoQ Step	Normal project stage	Typical example
1. Gathering project information	Desk study	Collecting historical and geological maps and other information
2. Risk identification		Discovery of old maps showing a filled-in watercourse crossing the site
3. Risk classification	Normally done during the Ground investigation stage, when the magnitude and extent of the hazard can be quantified	Prove that channel is up to 10m depth and infilled with soft organic alluvium
4. Risk remediation	Normally done during design , when the development can protect itself against the main risks	Design of different foundations for that part of the site; inclusion of methane protection measures for basement
5. Risk evaluation	Prior to tender ; collection of unmitigated risks so they can be managed / transferred to the contractor as part of the contract documents	Assess remaining extent of issues connected with channel
6. Risk mobilisation - filling in the risk register		Highlight to contractor that his plant may get bogged down in alluvial formation; care of piling rig stability

The risk-driven GeoQ process demonstrates the need for timely and adequate site characterization, appropriate geotechnical design and effective monitoring during geotechnical construction and for some projects even during operation. These activities are often under-resourced and are frequently the first to be cut when pressures to save project costs are applied. Systems are useful, however, like any system also a risk system cannot guard against a fundamental mistake being made by individual professionals or their teams. It just gives warning if the compensatory effects that might negate the consequences of the risk coming about are lacking. Thus application of a risk mitigation process like GeoQ or any other process should be viewed as a warning about the vulnerability of a project – not as a predictor of success or failure.

4 PREPARATION FOR PROJECT START

4.1 Gathering project information

As much effort as possible should be invested into gathering pertinent data in advance – the so-called “desk study” phase (BS5930; BSI, 1999) or “preliminary investigation” (Eurocode 7; CEN, 2004), followed by the “ground investigation” or “design investigation”. This information is usually relatively cheap to acquire compared to the consequences of the risk not being identified during construction. As an example for large office buildings in the UK, the substructure represents perhaps 5% of the construction budget and yet 50% of the risk of significant programme delay flows from that part of the project. Despite this only 0.5% of the project budget is typically spent investigating those risks in site investigation (desk study plus ground investigation). The emphasis on gathering good data can be increased by improving communication with the rest of the project team - for instance terming the desk study a “geotechnical hazard assessment” and concluding with explicit hazards, fits better into the general risk management process that may be used on the rest of the project. And those risks can be appraised and managed explicitly by the geotechnical team using the six GeoQ steps for appraising project information.

4.2 Early risk mitigation

Once the risks have been discovered and considered, it is possible at this stage to devise ways to reduce their impact or consequences if they do come about - preliminary pile load tests can be hugely useful both for economy (how small can I make the piles?) and also for reliability (how big must I make the piles?). However, often they are done too late in the process so there is too little time to react to their results. Working pile tests carried out during construction can be more risky - an unexpectedly poor result casts doubt on all the piles just formed, as well as creating uncertainty about the remaining piles yet to be built. Yet working pile tests cannot result in improvement as only in extreme circumstances do they tell you anything about the margin against failure. These risks to construction programme can be mitigated by doing more preliminary load tests at a very early stage and using the added confidence in the results to design and specify piles, with no need for reassurance by working pile load testing during construction. Thus full benefits are gained in terms of prudent economy with minimal risks of poor test results causing significant delay during construction.

4.3 Geotechnical Baseline Report

In a similar way, Geotechnical Baseline Reports (GBRs) now being introduced for tunnelling projects significantly reduce the risk of delay when something unexpected happens by imposing clarity of assumptions on the whole construction team. In the event that something unexpected happens, then the team can quickly identify who has contractual responsibility for remediation. Also as responsibility is clear, there is much less need for the high costs and long timescales needed to resolve a dispute using the legal process. The preparation of GBRs for more aspects of underground construction is encouraged.

4.4 Procurement

Probably the opportunity for most risk reduction occurs at the procurement stage, yet this stage can often be neglected by geotechnical designers who are more at home with complicated computer analyses implementing complex models rather than contractual clarity and communication. Often geotechnical designers will have long completed their input when the construction phase is being procured and all their knowledge of hazards and site features are overlooked by the procurement professionals. The form of contract has a large influence on how well problems will be managed.

5 RISK MANAGEMENT DURING CONSTRUCTION

5.1 Context for individual construction projects

The prime motivation for construction developers is to make money – either by the operation of the facility being constructed (such as the developer of a factory), or from the later sale of a well-performing asset (such as a commercial property developer).

Most significant construction projects are the subject of major financing deals. Financing a construction project requires a cost model to compare the initial investment with future returns, factoring in the cost for the finance. These models are very dependent on the out-turn construction cost and the start of delivery of financial returns. Usually the completion date is the most critical factor, as its postponement delays the start of revenue flows.

Many developers bear the financial risk themselves, and if things go wrong in a way that invalidates the assumption in their financial model, they are left to sort out the consequences. The usual main problems are delays causing late handover (delayed receipt of income streams), or higher cost. Often a disappointed developer will wish to recover losses from his design and construction team, for instance by liquidated damages for delay from the contractor or via the designers' professional indemnity insurance policies. These are not reliable methods for recovering losses, and especially consequential losses. Better ways of covering risks are to insure them explicitly by project insurance that covers the whole team, or by latent defects insurance (LDI) that covers the final building (although LDI doesn't always cover consequential losses). While these insurance products encourage a shared approach to resolving problems, they don't let designers and constructors completely off the hook as the insurer may later decide to try to recover some of his losses (by a subjugated claim), for instance if he suspects negligence was a cause.

5.2 Observational method

Management of ground risk by monitoring and contingency measures gained respect following the introduction of the Observational Method (Peck, 1969; Nicholson et al, 1999). The production of the latter report was delayed, as it was being written during the time that the Heathrow rail tunnel collapsed, and the authors had some difficulty in persuading the UK safety authorities that such methods were safe and could be safely advocated. They therefore had to be very explicit in the report with the steps that were essential for construction control using OM techniques to be seen as a responsibly safe approach. The steps proposed in the CIRIA manual are therefore a rigorous and safe way of constructing while taking advantage of the Observational Method.

5.3 Slope instability risk control

Management of the geotechnical risk in an environment of slope instability can provide significant economic benefits. Naismith and Wessels (2006) describe an open pit mine case history in which the introduction of a slope stability radar monitoring system allowed a large amount of ore to be mined which otherwise would have had to be abandoned or mined far less economically. Mine workers were evacuated from the pit less than 2 hours before a slope collapsed - there were no injuries, nor damage to equipment. A further example is that described by Cahill and Lee (2006) in which, owing to the use of slope stability radar monitoring, an open pit was able to continue mining for a year longer than would have been the case without the system and its contribution to risk management. The economic value of this was very significant.

The use of enhanced construction control can therefore be seen as a valid component in controlling geotechnical risks, and may be used with reduced factors of safety provided the management processes, which may include monitoring, setting of alarm levels, evacuation procedures, etc, are reliably rigorous. An example of a development in this area is that described by Mercer (2006), who presents a method for real time prediction of the time to failure of rock slopes. This method can make use of a variety of alternative monitoring data, including survey prisms and slope stability radar output. A similar technique could be used for any civil engineering excavation or structure provided suitable displacement data can be obtained at regular intervals. This development provides a powerful risk management tool, particularly as far as safety is concerned.

6 RISK MANAGEMENT DURING MINING OPERATIONS

6.1 Context for mining operations

The prime motivator for a mine operator is to make money, safely. In large quarries and open pit mines, the design and control of slope angles are of critical economic and safety importance. The value of a single degree of slope angle can be very significant – in an open pit with a depth of about 300m, this value has been shown to be about \$30 million (Little, 2006). The magnitude of this saving or cost will increase with pit depth.

The efficient operation of the mine is a pre-requisite, but the profits derive from the sale of the minerals or ores, the prices of which are determined by the international market, and over which the mining company has no control. Mineral prices often fluctuate widely, for many reasons, and therefore it is essential that risks are reviewed regularly so that the management of these risks can be adapted to optimise the mining operation. Because of the volatility of supply of, demand for, and prices of mineral products, mining companies need to carry out risk assessment and re-design on a regular basis, perhaps even as frequently as once a year. An example of such a case, described by Little et al (2007) follows briefly.

6.2 Mining case history

Anglo Platinum's Potgietersrust Platinums (PPRust) operates 3 open pits and plans to excavate 90Mt of rock in 2007. With pit slopes expected to reach a height of 500m, geotechnical engineering has a key role to play. Over the last four years PPRust has successfully implemented new geotechnical strategies and tactics to reduce risk, improve safety and maximise profitability. A large database of core logging, face mapping and rock testing data has been assembled and used for failure analysis, geotechnical zoning and rock mass ratings. The data have also been used for optimising blast designs on a daily basis through the use of a geotechnical block model similar to the ore grade block models commonly used in mine planning. This greatly improves blast fragmentation and therefore loading, hauling and milling efficiencies. Over an 18 month period in 2002 and 2003, the improved milling efficiency on its own resulted in additional revenue of \$4.5 million (Bye, 2006).

Anglo American has adopted an approach to its open pit operation in which the level of risk acceptable to the company is specified, and the design of the pit and its operation are then carried out to ensure compliance with this risk level (Little, 2006; Terbrugge et al, 2006). The slope design process involves limit equilibrium analysis, numerical modelling, rock fall analysis and block modelling. Slope management includes comprehensive design and control of blasting, visual inspections, and state-of-the-art slope monitoring equipment, namely GroundProbe slope stability radar, Riegl lasers and GeoMoS automated prism monitoring. The risk-consequence approach has been used in slope optimisation, where all the slope analyses, operational controls, costs of failure, economic analyses of various slope designs and fault tree analyses are used to determine the ideal slope designs. These activities have added over \$25 million of value to the operation, and also ensured compliance with Anglo American's acceptable risk level.

The successful mining of the optimised slopes is due to the greatly improved geotechnical knowledge and slope management. PPRust's geotechnical work is used as a benchmark for Anglo American open pit operations. The cost of the slope optimization exercise and the slope management measures (management of operational risk) has been approximately \$1 million, a fraction of the value that has been gained from it (Little, 2006).

This case illustrates clearly that focus on value rather than on cost cutting (the latter being the common focus in the mining industry) results in better safety, better efficiency and better profitability. The adoption of an acceptable risk basis for design is commendable, since it ensures that decisions on the level of risk are taken at executive level. Such risk decisions are strategic ones, and it is appropriate that they are taken at the highest level. The quantification of risk in both potential loss of life and financial terms is important since it "demands" hard management decisions to ensure risk compliance.

7 REACTIONS TO GROUND-RELATED PROBLEMS

In dealing with a natural material like the ground, there will always be unexpected situations. Sound risk management in the earlier phases should reduce their impact, but will never eliminate their occurrence.

When an unexpected situation arises with the potential to cause major delay or cost escalation, or have safety implications, some basic steps are always appropriate. These include: immediate communication to members of the project team, particularly the Client, gathering of relevant data and proposals for mitigating the problem.

The *easiest* way to resolve a problem is in a no-blame environment; the *quickest* way to resolve it is for the whole team to pull together and to use the best skills available to agree ways to remedy whatever has gone wrong, rather than to argue about whether a problem exists and who should bear responsibility for it. As the consequence of delay often ends up as the largest cost, rapid resolution of the particular problem limits the financial exposure for whoever eventually ends up as being legally responsible, and has to pay for the problem. For this reason, many major projects carry project insurance, or use “latent defect insurance” / decennial insurance to cover costs in case things go wrong, and to allow the team to concentrate on efficiently solving any problems that arise.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

John Ruskin (1819-1900) wisely said, a very long time ago:

"It is unwise to pay too much, but worse to pay too little; when you pay too much, you lose a little money, that's all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the things it was bought to do. The common law of business balance prohibits paying a little and getting a lot. It can't be done. If you deal with the lowest bidder, it is as well to add something for the risk you run. And if you do that, you will have enough to pay for something better. There is hardly anything in the world that someone can't make a little worse and sell a little cheaper – and people who consider price alone are this man's lawful prey."

This statement is as true of construction procurement in the twenty-first century as it was when he first wrote it. Unfortunately many construction clients do not select their designers or constructors with the same clarity of purpose that they use to choose their heart surgeon or property lawyer.

8.2 Recommendations.

It is down to providers of professional services to educate their clients to understand the critical risks that they face and how to react to them.

In some cases, clients (or their representatives) will have fixed views and the geotechnical professional will be too far down the pecking order to influence the decision making process. In these circumstances, the geo-professional must write recording the correct approach, so that responsibility for incorrect decisions can be traced. In doing this, he will have the support and encouragement of his provider of professional indemnity insurance.

It is usually more helpful to write outlining probabilities with risks. Otherwise the client may perceive that the risk is a high probability, and when it doesn't come about, he will think that he was right to cut the corner, and his geo-professional advisor was wrong. So for instance, rather than just warn that a slope may fail, it is of much more use to warn that based on current knowledge there is a 25% probability that the slope might fail, and if it does fail there is a further 50% probability that the main road servicing the site will be cut. Thus the client will appreciate that the probability of the main road being cut is 12.5%, and can balance the cost and programme consequences of it closing his site for a month (the financial risk) plus the safety risk for road users with the effort needed to stabilise the slope. The important thing is if the project is completed without the slope having failed, the client does not feel that his approach was vindicated, but instead has a feeling for the margin by which he avoided calamity.

In general, those people who make more money in life are often those who are prepared to take more risk. One of the reasons for the meagre profits which designers generally make on projects is also due to the fact that they are unwilling to accept more risk. This to some extent is a vicious cycle: they don't take on more risk because they can't afford to do so. A reason why they can't afford to is because the level of potential profit is kept very low by relatively stiff competition, some of it by competitors providing a less comprehensive service.

It is the authors' contention that designers should be prepared to share project risk in appropriate circumstances, for added reward, *provided the risk is properly managed*. For this to happen, the designer has to be in a position to control the risks that he is taking on. He must have a say in the decisions about processes that will be used to control the risk, even beyond the design phase. The incentivisation structure must link his reward to a fair outcome. The client must view the added designer's role as a way of improving the likelihood of a successful outcome rather than as a way of shedding risk at low cost. This approach will ensure that frank discussions take place about the risks on the project, the methods by which they can be controlled, and the client's ability to carry them.

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