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Failure as a Yardstick for Prediction Ability

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1 INTRODUCTION

The theme of the 5th Australia-New Zealand Geomechanics Conference is "Prediction versus Performance" and of this session "Failure as a Yardstick for Prediction Ability". Only six papers which relate to the theme have been submitted and all happen to come from New Zealand. This should not be taken as implying that failures only happen in New Zealand or that New Zealanders have a more honest and open attitude to the things that can (and do) go wrong in geotechnical projects. I will return to that point later but first I would like to discuss the meaning of "failure".

2 CATEGORIES OF FAILURE

To some people "failure" implies a highly conspicious event - blood all over the carpet; red faces all round; witch hunts for scapegoats. That is the way the media loves to publicise them and such events I will call "overt failures". Overt failures do occur, but in relation to the very large number of geotechnical projects completed every year they are very rare. While such events can provide very valuable (but costly) lessons to all of us, their rarity makes them more like "national standards of length" rather than "yardsticks" for day to day use. Many of these events are made public through inquiries or legal cases. Both these methods have a tendency to focus on the aspect of "blame" rather than on the geotechnical factors of the case. Avoidance of "blame" is an important aspect of professional practice. But it is not necessarily well related to the natural principles which underlie the practice of the geotechnical art. So overt failures are not very effective yardsticks for day to day use in improving our prediction abilities.

Then there are the "secret failures" - the skeletons carefully buried in un-consecrated ground. Keeping such failures hidden from the public becomes such an obsession that even when the corpse is accidentally discovered, the stench of corruption is so overpowering that the geotechnical reasons for its demise get scant attention. These sorts of failures also are poor yardsticks for geotechnical prediction ability: but they may be useful for measuring human frailty!

A third category of failures are every-day events which do not necessarily lead to collapse or overt disaster. They are an integral part of the geotechnical context and crop up almost every time a geotechnical prediction is made. It is an essential component of the art of geotechnical engineering to recognise the frequency with which geotechnical forecasts fail to predict the way things turn out, always to leave enough room for maneoeuvre and to keep continually alert to the need to make adjustments to concepts and details when the prediction becomes unacceptably inaccurate (or downright wrong!). It is these every-day failures of prediction that I believe provide the yardsticks against which we would assess our prediction ability. We all experience them all the time and woe betide any of us who is lulled into a sense of security by the "power of the basic principles", the "elegance of the solution" or the "accuracy of the mathematical analysis" that have been applied to the problem. Mother Nature has ways of dealing with such intellectual arrogance. In the game of geotechnical chess that we play against her we must endeavour to achieve at least a draw. But remeber that one or more of Mother Nature's pawns may turn out to be queens in disquise and her rules may not be exactly as we believe them to be.

3 PAPERS PRESENTED

But to return to the six papers which relate to the theme of this session. They are:

* Predicting Landslide Mobility, an Application to the East Abbotsford Slide, New Zealand, by N Smith and G Salt.
* The Kaimai Tunnel, by J D Bennion.
* Matahina Dam: The Initial Lake Filling Incident and the Long Term Performance of the Repair, by M D Gillon and C J Newton.
* Design and Construction Aspects of the Maniototo Scheme Paerau Diversion, by B R Paterson, G Ramsay and D W Jennings.
* Canal Failure, Ruahihi Hydro-electric Power Scheme, Bay of Plenty, New Zealand, by L E Oborn.
* Canal Failure on the Wheao Power Scheme by O T Jones.

For convenience these papers are referred to by the relevant place name which have been underlined above. They are listed in the associated alphabetic order.

In discussions on the format of the Conference it was agreed that the New Zealand Geomechanics Society would take responsibility for this session and would if necessary provide some input to it as well as the session reporter. In the event no papers were offered for the session and NZGS had to make good its undertaking. So they commissioned the above six papers, each one of which deals with an aspect of a geotechnical project in New Zealand which attracted publicity and would be considered an "overt failure" as discussed above. Not all the papers discussed the whole event concerned and it is therefore appropriate to add a few comments here concerning the degree of public exposure each received.

Abbotsford was a very public event since it involved about 20 ha of residential properties over 60 of which were directly involved. The incident was the subject of a commission of inquiry set up by central government.

A fatal accident which killed four people occurred during the driving of the Kaimai tunnel. This accident was investigated by a commission of inquiry and was extensively reported in the media.

The Matahina leak was discussed briefly during the 5th Australia-New Zealand Conference on Soil Mechanics and Foundation Engineering in Auckland. It was also briefly described by Sherard in the Casagrande Volume of Embankment Dam Engineering. There was no formal inquiry.

The Paerau Diversion was part of an irrigation scheme which, because of large cost escalation, attracted much political attention. Media attention focussed on the politics and the technical difficulties of the work were not discussed publicly.

The Ruahihi collapse was very visible and was given extensive coverage by the media. Technical aspects of the incident were investigated by a committee of inquiry set up by the Commissioner of Works whose report was subsequently released.

The Wheao collapse, which occurred within 18 months of Ruahihi, was widely covered by the media. Technical aspects of the incident were investigated, in public, by a committee of inquiry set up by the Minister of Works.

In such a geographically compact country as New Zealand it is inevitable that your general reporter will have some prior knowledge of all six cases. In fact he was directly involved in three of them. But in discussing the papers presented and attempting to draw conclusions from them he will endeavour to avoid drawing on such prior knowledge.

4 SUMMARIES OF PAPERS

4.1 Abbotsford

A sizeable area of settled land in the community of Abbotsford slid out in August 1979 destroying, or badly damaging over 60 houses. While signs of movement had been apparent for some time the final slide was very rapid. Initial deformations of about three metres took place over a period of several years while the final displacement of 50 metres occurred within 30 minutes. The failure surface was essentially plane and slide movement translational. The paper is concerned primarily with discussing the reasons for this rapid acceleration in the failure rate. It concludes that:

* Residual conditions probably existed immediately before the rapid movement started and that further degradation of strength due to shear displacement is an unlikely explanation for the final acceleration.

* Pore pressure changes in sandy layers immediately adjacent to the sliding surface (which lay in a thin clayey stratum) were unlikely to be sufficient to explain the rapid acceleration but could have been a contributory factor.

* Frictional heating of the sliding surface causing the pore fluid to expand and thus raising the pore pressure in the vicinity was a plausible cause of the rapid acceleration. This is confirmed by preliminary calculations using a reasonable velocity/time function and realistic material properties. Definitive calculations have not been carried out for lack of precise parameters.

4.2 Kaimai

The Kaimai Tunnel was driven through a complex geological profile of dipping lava beds and volcanic materials. The cover over the tunnel was large (over 400 m for half the tunnel length) and the topography rugged and heavily vegetated. Thus, although 3,700 m of borings were made much of the tunnel line could not be drilled. At the Western portal, where the ground was fault scarp generated colluvium, and at the 4 km mark, where a buried debris slope was found, tunnelling conditions were very difficult and the way these conditions were overcome is briefly described. A collapse at the Western portal took four lives. This is the only "failure" mentioned in the paper and in its conclusions the paper contrasts this accident with the successful completion of the more difficult section at the 4 km mark. The difference is attributed to the greater skill and experience brought to bear in the second case.

4.3 Matahina

The Matahina dam was completed in 1966 and the reservoir filling commenced at the end of the year. During filling here was a sudden pulse of turbid outflow from the drainage system. Some two weeks later a subsidence appeared in the right abutment just downstream of the core. When investigated this was found to have originated from a crack in the core through which reservoir water had penetrated and eroded downstream transition material. This defect was repaired and appeared to give satisfactory service for 20 years till the dam was struck by March 1987 earthquakes. This produced accelerations of up to 0.48 g in the dam and caused some visible damage, including minor cracking and delayed settlement in the area of the 1967 repair. In the course of investigating these earthquake effects the original repair was opened up and its condition evaluated.

The paper summarises the history of the original incident and its repair as well as describing the state of the repair after the earthquake. (Further phenomena have been found since the paper was written and are still being evaluated). Amongst other things it concludes, in relation to the original repair:

* The importance of full compatibility in dam materials under all likely conditions.

* The great significance of "as built" and surveillance records for dams.

* The ineffectiveness of grouting in the body of fill type dams.

* The value of specialists from other disciplines in interpreting geotechnical phenomena.

* The time scale of the appearance of earthquake effects can be considerable.

* The 1984 filter criteria of Sherard et al are applicable.

* Beware of the unexpected effects of sandbags.

* The original repair had been effective, though it had leaked slightly to begin with.

4.4 Paerau

The Paerau diversion was constructed through pelitic schists whose strongly marked anisotropy was recognised during investigations and allowed for in design. Canal profiles were developed during design which were considered to be adequately stable in terms of the measured rock properties and attitudes and the stability of natural features. In the event continuous thin foliation shear planes coated with low strength gouge caused substantial sections of the deeper cut batters to slide out. Rock conditions were not expected to cause tunnelling difficulties except at known fault zones. These expectations were borne out in practice. The paper concludes that:

* The conventional drill hole spacings of 200 m were inadequate to locate and correlate the troublesome foliation shear planes in this rock.

* The low relief topography through which the diversion was routed may have been a zone of inferior rock.

* The full significance of the rock structure was underestimated but an inter-active design/construction process allowed successful completion of the canal excavations.

* The squeezing conditions encountered in the fault zone traversed by the tunnel were unlikely to have been recognised in drilling investigations.

4.5 Ruahihi

The day after the Ruahihi hydro-electric power station was opened by the Prime Minister of New Zealand its headrace collapsed, causing substantial damage to property but, fortunately, no loss of life. The paper outlines the very difficult foundation materials of the site and the engineering solutions adopted to counter some of these. The series of disturbing phenomena preceding collapse is recounted and a possible failure mechanism put forward. All of this information is condensed from the report of the committee of inquiry and submissions made to it.

The author concludes that:

* The only merit in reviewing past disasters lies in the lessons they may teach.

* The very adverse nature of the soils along the canal route were not adequately allowed for in the design of the canal and its lining system.

* There was poor continuity of thought during the protracted process of investigating the site and building the works. Early indicators of possibly troublesome conditions were not always followed through.

* The need, when geotechnical conditions are adverse, for planners and designers to stand back from day to day concerns and review the situation dispassionately. Peer review is a powerful mechanism for achieving this and specialists should be called in when necessary.

4.6 Wheao

The headrace canal of the Wheao hydro-electric scheme was built across a volcanic plateau with unusual characteristics. During commissioning the canal collapsed at its downstream end, wrecking the powerhouse but without causing loss of life. The paper briefly describes the scheme and its geology and gives information on the collapse and antecedent phenomena.

The probable failure mechanism is summarised and the lessons to be learnt from the collapse are set down. These lessons are:

* The great significance of the interface between an impervious earth lining and rigid structures such as intakes. Provision must be made for the differential movements which are to be expected at such interfaces.

* Fine-grained non-cohesive volcanic soils of low mass density are very susceptible to piping.

* Open joints in volcanic rocks provide potential starting points for piping in overlying soils and project development may increase seepage effects at such critical points beyond safe limits.

* The merit of a multi-layer self-monitoring lining system for canals whenever the foundations are particularly susceptible to seepage effects.

* The need for continuing geological involvement when geotechnical conditions are complex and the benefits of a peer review system.

The collapse has been repaired and the scheme has been in full service without significant incident for four years.

The paper is essentially a summary of the report of the committee of inquiry which was chaired by the author.

5 COMMENT

While all six papers are concerned with geotechnical aspects of developments which suffered some form of mis-adventure not all are strictly relevant to the theme of "failure as a yardstick for prediction". However, taking a broad view of the information given it is possible to draw some general conclusions relevant to that theme.

The first of these is the need to remain alert to the possibility (or even the certainty!) of the unexpected. At both Abbotsford and Paerau sliding occurred along very thin layers of wide extent and

and planar shape. Was it likely that the existence of such a thin (10 - 20 mm) weakness would have been identified in normal investigations as a continuous, extensive feature? And, if this is not likely, what should be done to reduce the probability that such critical features will be overlooked. There is a very relevant fable about low probability tigers and cannibalistic ladies which is recounted in "Engineering Risk (ref. 1) and which all practitioners of the art of geomechanics should continually bear in mind.

The second is the need for humility in preparing to face the unexpected. None of us is omniscient and the rigour of an analysis or the power of a concept does not give any assurance of its relevance to a particular case. The value of "outside" specialists is mentioned in one or two of the papers and the benefits of the peer review technique in several. These are powerful means by which eyes can be kept on the whole forest in spite of the many trees!

The third is the persistence of the human spirit and the vast reserves of ingenuity that it can bring to bear when the unexpected develops into the disastrous. In five of these six cases when disaster struck the project was successfully saved and is now back in satisfactory service. These resources are more effectively deployed in recognising the unexpected at an early stage and bringing it within the parameters of the design so that it does not develop into a disaster.

A fourth question that arises is why were there no papers offered on the theme of the session? Why was it necessary to commission papers? Does this suggest that we only admit to the possibility of failure when someone twists our arms? Or are failures, like middle age, something that only other people suffer from? This coyness in the face of the real situation is in marked contrast to the sermons we all preach about the need for "free exchange of information", "learning from experience" and other pious shibboleths! This is probably the most important point about this session. We as a group, are not prepared to make our less happy geotechnical actions available to our peers for examination. Equally damningly we are not above making harsh criticisms, allocating blame and scoring debating points when we do come across someone else's unfortunate but none-the-less informative experience. Under such circumstances the day-to-day failures of imagination, judgement or even of arithemetic that we all experience in geotechnical work will never become more than private yardstick - and then only if we remain alert to them. The few overt failures which receive dispassionate geotechnical evaluation free of one-manship will remain as rare signposts on the road to technical excellence. But many of the signposts erected by inquiries into overt failures are flawed by the influence of legal niceties or commercial interest. Geomechanics is concerned with the Laws of Nature (which we understand only imperfectly) and these laws are not influenced by the Laws of Man!

6 PANEL DISCUSSION

This session is planned to include a discussion of a few key questions by a panel of four experts. To emphasise the Regional nature of the conference and the wide scope of geomechanics I have asked the organisers to try and satisfy the following criteria in selecting the panel members.

a Two members from an Australian background and two from a New Zealand background.

b One from each of the three disciplines of soil mechanics, rock mechanics and engineering geology.

c At least one from the area of engineering practice and one from an academic/research institution.

All these backgrounds needs to contribute if conclusions are to have any general relevance.

The three questions which I consider the panel should address are:

i How can we ensure that the day-to-day failures of prediction that we are all subject to become available to the profession as neutral technical information? Is our individual reluctance to expose our feet of clay a greater hindrance than our keenness to feel smug about the misfortunes of others?

ii How do the precision of mathematical analyses and the rigidities of fundamental concepts compare with the rather fuzzy information about the geotechnical context that is available. Should we replace the term "factor of safety" with one such as "margin for uncertainty"? And what margin should be allowed in predicting performance from the results of analysis?

iii What techniques are available for the identification and correlation of thin defects or weak layers in geological formations and how can their significance on a large scale be better recognised in specific cases?

7 REFERENCES

STRACHAN, C.M. et al: Engineering Risk: Institution of Professional Engineers New Zealand 1984.