

SESSION 12 – GENERAL REPORT SLOPE STABILITY

Reporter
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This session attracted only seven papers, which is obviously disappointing, being rather biased in this area. With this number of papers, large subject areas in the field of slope stability have inevitably not been covered, or only briefly discussed. I do not, of course, imply that the papers presented were in any way substandard; rather that a greater number were needed to adequately cover the field.

Table 1 shows a breakdown of the topics covered by, or mentioned, in each of the papers. They have been arranged by principal author only in this table.

Principal Author	TOPIC														
	Soil Mechanics	Rock Mechanics	Civil Engineering	Mining	Strength Parameters	Safety Factors	Probability	Finite Elements	Modelling	Fracture Parameters	Back Analysis	Earthquake Forces	Tailings, Dams	Groundwater Effects	Rock Modulus
ADIKARI	X	X			X	X									X
CHOW WEI YUAN		X	X		X	X		X	X						X
CHOWDHURY	X	X			X	X									X
ECKERSLEY		X	X	X											X
JAMES		X	X		X					X	X				
NGUYEN	X	X	(X)	X	X					X				X	
TRUSCOTT		X	X				X	X							X

TABLE 1 - Analysis of Papers Presented

There was an even split between soil and rock-related papers, with a distinct bias to the civil rather than mining engineering fields. Three papers dealt with finite element assessments of stability, all from different viewpoints, whilst only one paper looked at variability, fracture parameters or earthquake forces.

I shall first give some commentary on the individual papers in the session, and then discuss the areas which require further input in the future.

1 REVIEW OF PAPERS PRESENTED

Nguyen presents the use of a mathematical technique to 'zero-in' on geomechanical parameters at failure in a slope, using back-analysis. The technique has a rapid convergence to conditions satisfying equilibrium, but the results are still dependent on the initial estimates for the parameters. This suggests that with perhaps triaxial or shear test results, a better 'first estimate' can be input to the back-analysis. Otherwise, sensitivity analyses on each variable still need to be run to see how sensitive the result is to the initial values chosen. It would perhaps be possible to have an iterative program which could carry out this sensitivity, varying the base value of one variable at a time.

Chowdhury discusses the derivation of a probabilistic infinite slope analysis which reflects the spatial variance inherent in soil properties. We all understand that failures in soil tend to occur over a width that is related to their length. This is a topic which no doubt will continue to be analysed in the future. The reviewer was interested in the magic ' δ ' length however, which was quoted as 'denoting, in the physical sense, the size of hard and soft pockets in a heterogeneous medium'. I would liken this to a geostatistical modelling problem, where ' δ ' represents perhaps the range beyond which geomechanical parameters measured from boreholes, etc., are independent. I would like to have seen some discussion of the justification for the δ values used in the examples given in the paper.

The paper by James is a particularly interesting approach to back analysis. Of particular interest is the comparison between the inwardly inclined exterior construction versus the horizontally layered one. A form of active-passive wedge failure can be postulated for the former, which yields lower safety factors than an equivalent horizontally bedded structure for the same friction angle. Possibly this was the failure mechanism on these pyramids when failures occurred? (The author does not state which back analysis method was used.)

Living in Papua New Guinea however, I have to disagree with the safe slope angles for horizontally layered limestone. We have a 660m (2,200 ft) vertical 'wall' of horizontally bedded limestone near us, which though failing on occasions through undercutting, is surely in terms of 'time dependence' a vivid exception to this rule. The slope achievable is surely a function of the 'block size' or the vertical distance between planes of weakness.

Adikari and Tan discuss the application of finite element models to the determination of dam/embankment constructions. The ability to handle stability

analysis of non-horizontal, multiple layered constructions with finite elements is, I feel, a definite advantage over the normal two-dimensional techniques. I was surprised to see that the critical circle appeared to have to be located in the analysis. Could not a program be written to search for a critical surface on the basis of maximising the finite element stresses within physical limits? Also,

- (i) if three-dimensional finite element models can be constructed for this type of analysis, then side forces could be computed. This would then be a genuine three-dimensional analysis.
- (ii) the authors do not mention the effects of water pressures in the finite element approach - any reasons?

The papers by Truscott and McFarlane, and Yuan et al, also use finite element methods to analyse rock stability, though in different ways. Truscott's analysis of cutting stability due to subsidence I found interesting. However, the lack of consideration of existing discontinuities in the rock on the resulting stress distributions (and hence likelihood of inducing tension cracking for example) seems perhaps to be a drawback to the use of the finite element system in this 'small-scale' environment. Yuan meanwhile uses finite elements in the classical way to analyse dam abutment stability. The comparison with model testing, and the simulation of frictional and strength properties in the modelling, was also of interest.

Finally, Eckersley has analysed the behaviour of slides in coal stockpiles due to liquefaction following rainfall. It is of interest to consider the extension to loosely tipped run-of-mine stockpiles in areas of high rainfall, and the correct way to analyse their stability. Obviously the undrained triaxial strength parameters can only apply at the onset of failure, rather than during it. The determination of the likely extent of a slide is of interest to mining companies in sensitive environments.

2 DISCUSSION

The papers were collectively disappointing in their extent, with some of the following items not covered or considered only by one paper.

- (i) There was a complete lack of open pit slope design work, either of a research of implementation nature. It is hard to believe that no one is doing anything either novel or practical enough to warrant reporting on.
- (ii) Only one paper looked at variability in soil strength parameters, and the influence on some aspect of predicting failure extent or likelihood. Over the past few years the industry has come to accept the use of modelling variability in slope design, and there are many areas of research in this field which require elaboration. Of particular note in this regard is the ability to model full-scale shear strength parameters in rock slopes, and the need to consider discontinuity orientations, lengths, spacings and waviness as an integral structure to obtain the rock mass strength in a given orientation.

- (iii) Tailings disposal, and tailings dam design, seems to have been neglected of late. Considering that it is an environmentally hot potato, it is surprising that more work on looking at uncertainty in design hasn't been published.

A basic problem which seems to be emerging in the slope stability analysis field, is that our manipulative tools (eg, probabilistic analyses) are outstripping our ability to predict the parameter values influencing the analyses. For example, in the paper by Nguyen pore pressure effects have been handled by the use of 'r', whilst the strength parameters are given with means and standard deviations. If r cannot in itself be treated as a variable (time or spatially dependent), then surely any probabilities of failure for an analysis should be plotted against r to understand the sensitivity of the estimate of this parameter to the analysis.

This is not aimed as a criticism of the paper. I would contend that even with measuring shear strength parameters, or in rock perhaps fracture orientations, and quoting their means and standard deviations, we can easily

- (i) overlook scale effects in the analysis;
- (ii) omit to determine what portion of our measured variability is due to the limitations of our testing or measuring procedure.

This I hope highlights my point that we can treat probabilistic approaches as a 'black box', believing the results without appreciating the limitations inherent in the analysis. I believe that more consideration should be given to efforts to isolate the 'true' and 'observed' variation in modelled parameters, so that perhaps a true 'confidence interval' can be placed on our predictions of failure probability, etc.

To finish on a brighter note it was interesting to see some positive moves in the papers presented, including

- . the use of finite element modelling as a stability evaluation tool
- . further development in the use of probabilistic methods to soil slopes, and
- . alternative and novel methods of back-analysing failures to obtain failure criteria

It was stated at the ISRM conference in Melbourne last year that we were in a period of 'consolidation' in rock mechanics in general. Whilst that may be true in terms of major new concepts, there is still a long road ahead to refine and use as practical tools the finite element, probabilistic, and other mathematical methods which we have now had introduced to this subject. The papers presented in this session represent steps towards achieving that aim.