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13 March 2002

Dear Dave

This letter report provides comments on some aspects of the results obtained from recent dynamic testing of the yielding strand anchors.

Firstly, I will comment on general aspects of the testing facility and, secondly, I will comment specifically on the test results.

TEST FACILITY

The results and interpretations may be affected by factors related to:

- Test Equipment and Testing Procedure
- Instrumentation and Monitoring System

It must be kept in mind that I have not physically observed the equipment or testing procedure. The comments provided are based on my understanding of basic mechanics associated with hydraulic loading systems and possible reinforcement responses.

Test Equipment and Testing Procedure

There are at least two issues here.

How does the equipment provide loading to the test specimen?

It is assumed that loading is provided by hydraulic fluid flow into a solid ram cylinder. The rate of displacement will be controlled by the rate at which oil flows and the volume of flow will depend on the total displacement. There is a possibility that the performance of the equipment will therefore depend on the stiffness of response to loading provided by the reinforcement. That is, the performance of the equipment may vary between providing rapid loading over a short travel length compared with loading over a longer travel length. A greater rise in oil temperature would be expected to be associated with larger volume flows (both rate and volume).

How representative is the test of dynamic loading of reinforcement associated with a strain or rock burst?

My knowledge of the testing procedure is as follows:

1. The test specimen is usually initially loaded to some pre-determined level.
2. The "bump" is then applied with the objective of achieving a displacement rate of approximately 3 m/s.

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With regard to initial loading, this may or may not be appropriate, depending on the system being tested; that is, whether it is capable in practice of being pre-loaded or would possibly have been loaded due to rock displacements after installation prior to the dynamic loading.

The second issue is in regard to the behaviour of the reinforced block system following impact loading. In practice, the block will have an initial velocity which should gradually reduce due to energy absorbed by the reinforcement. If the reinforcement is effective, the block will come to rest.

During the process of arresting block movement, the reinforcement load will increase or, in the case of a yielding system, may remain essentially constant until the block comes to rest when the reinforcement force will depend on other factors such as where the block release occurred (from the back or wall) and whether it remains in contact with the surrounding rock.

On this basis, the loading system does not really simulate the energy dissipation of a reinforced block system following initial impact loading. In particular, the total energy input to the system may exceed that expected in practice.

Instrumentation and Monitoring System

My understanding is that force is measured using an electronic load cell and this is monitored by a computerised data logging system. If the force is estimated by monitoring of hydraulic pressure, then my comments would be different.

This issue here is whether the load cell and monitoring system respond at a sufficiently high frequency to detect the actual force being applied to the reinforcement. The test results note that the scan rate is 1000 Hz (i.e. 1 scan per millisecond). The response time expected from the load cell is not known and it is therefore impossible to comment further.

TESTING OF YIELDING CABLE ANCHORS

Summary of Results

The results show an initially moderate resistance (~125 kN) followed by resistance which oscillates between ~ 50 kN and ~ 90 kN, with peaks and troughs separated by approximately 15 mm. On re-loading, the resistance returns close to its previous moderate level (~120 kN).

Interpretation

The obvious observation to be made is that the testing results are very difficult to explain.

However, some comments on general performance of frictional behaviour can be made. It is well known that static friction is higher than kinetic friction. That is, it requires a higher force to overcome initial resistance and initiate movement than to maintain sliding. Also, frictional mechanisms exhibit the stick-slip phenomenon

Firstly, it may be important to note there is a significant difference between the performance indicated in the current test results compared with previous testing results. The previous test results show very wild fluctuations of indicated force; for example, often ranging between increases up to 400 kN followed by drops to 0 kN. In the latest tests, these fluctuations did not occur. It could be surmised that because of the more efficient mechanism, yielding occurred more readily than with previous systems (e.g. Cone bolts in cement grout and the earlier version of your yielding mechanism).

Secondly, sliding will be accompanied by heat generation. This was observed in the quasi-static tests and the temperatures during rapid displacement would be expected to be higher. The heating will cause expansion of the components of the yielding mechanism. The effect of temperature rise and associated radial expansion cannot be accurately assessed but could be a potential cause of the lower frictional resistance. A reduction in the slip load would possibly occur if the coefficient of expansion for the hollow steel tube is larger than the expansion of the strand. However, it is not clear why the resistance returns to its original higher level as the duration of the test would not allow for significant cooling.

PRACTICAL IMPLICATIONS

Ultimately, the expected performance when implemented in practice is the most important consideration. In this regard, it is possible to assess the relative performance of the anchors in terms of energy absorption rather than solely based on the force-displacement response.

Static Force Capacity

The quasi-static tests performed in Perth and the pre-loading performed in South Africa prior to impact loading both indicate that the static capacity is consistently at least 130 kN.

Force Capacity During Rapid Loading

While there may be some doubts as to the reasons for the relatively low resistance observed during rapid loading, the acceptability or otherwise needs to be based on what might occur in practice; particularly recognising that energy absorption is based on the integrated product of force and displacement.

Energy Considerations

In the absence of specified expected energy releases and the required energy absorption of reinforcement, the following reasonably simple calculations are provided as an example of determining the acceptability of reinforcement systems and, in particular, the latest prototypes of your yielding anchor.

Example of Simple Energy Based Calculations

Assume the ejection of a block of rock with mass of 1 tonne per m² at a velocity of 5 m/s. The energy associated with this dynamic event is approximately 12.5 kJ/m². If reinforcement is installed in a square pattern of about 1.2 m, the energy to be absorbed by each reinforcement system is approximately 18 kJ (note this figure is comparable with 25 kJ often used as the design energy absorption required for reinforcement in very deep South African mines which are susceptible to major rock bursts).

If slip occurs at an approximately constant force of 70 kN, then the energy absorbed by the reinforcement is ~ 7 kJ per 100 mm of displacement. Theoretically, the block movement would be arrested within ~ 250 mm.

If it is possible to increase the rapid displacement slip force to ~ 120 kN, then the energy absorption would be ~ 12 kJ per 100 mm of displacement. For the same block, the block movement would be arrested within ~150 mm. However, as discussed, attempting to have a higher dynamic slip force may not be advisable or achievable.

These calculations show that the displacement and energy capacities may be more important than the dynamic force capacity (force at which slip occurs during rapid displacement), provided that the combined static capacity of the reinforcement scheme exceeds the weight of the rock block or combined mass released during a strain or rock burst event.

SUMMARY

A brief assessment has been made of the dynamic test facility and the results obtained for the testing of latest prototype of your yielding mechanism.

The key issues that have been identified relate to:

- The test procedure and how it may or may not simulate dynamic loading of reinforcement from strain or rock bursts.
- The measuring and monitoring system.
- The significant difference between the force oscillations observed in the latest testing compared with previous testing.

With regard to the your yielding mechanism, its adequacy in practice will be dictated by design specifications provided by a mine site. Simple calculations show it has the potential to absorb energies of at least 70 kJ /100 mm of displacement. Whether this is acceptable will need to be assessed by calculating the rock displacement associated with a specified energy.

I hope you find these comments useful. I would be very pleased to provide further explanation to yourself or any of your potential clients.

Thank you for the opportunity to be of assistance.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Alan Thompson', written in a cursive style.

Alan Thompson