Lessons in control of mine costs from instrumented cable bolt support case studies

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ABSTRACT: Instrumented cable bolt support [SMART – Stretch Measurement for Assessment of Reinforcement Tension - cables] was developed in Canada [Canadian Patent #2,200,834] and has been in use for the past three years. These instruments have achieved wide acceptance in the Canadian mining sector and are now being exported internationally. A significant case study database has been developed using SMART cables, SMART MPBX's and SMART contractometers under a wide array of mining situations and ground conditions. The instrumentation is routinely used today to help achieve both operational and safety goals. The paper briefly summarizes findings from various case studies that illustrate the positive economic impact this technology brings to operations, both from an economic and safety perspective. A recent case study illustrating cable bolt performance [measured load steps] under dynamic rock burst load conditions is discussed in detail.

1. INTRODUCTION

A recent handbook on cable bolting (Hutchinson and Diederichs, 1996) provides a comprehensive review of cable bolt support technology, including theoretical considerations (e.g., load transfer for frictional support elements), design methodologies and operational issues (e.g., quality control issues, etc.). The handbook involves three principal components: *Design*, *Implementation* and *Verification*. Whereas approximately 70% of the handbook is concerned with design and 25% with implementation, less than 5% is devoted to verification. The authors suggest that the verification process should involve an evaluation of the effect of cable bolts on rockmass stability, based on a combination of observation and instrumentation.

Quantitative verification is dependent on the ability to obtain a direct measure of the performance of the support element(s) in question. Previous attempts to directly instrument cable bolt support have met with very limited success, largely due to the measuring elements being mounted external to the cable. Early field results achieved using a novel cable bolt instrument, the SMART cable, which overcomes the major drawbacks experienced with earlier cable bolt instrumentation attempts have been presented [DeGraff et al, 1999; Ruest et al, 1998; Hyett et al, 1997]. The SMART cable permits accurate assessment of the deformations, and calculation of the loads, to which long cable bolt elements are subjected to during the excavation process (Hyett *et al*., 1997). Companion instruments, the SMART multiple position borehole extensometer [MPBX] and the SMART contractometer are used to compliment the SMART Cable instruments with measurement of rockmass dilation [SMART MPBX] and the closure of mined openings or the compression of pillars [SMART contractometer]. The findings discussed herein are all from underground mining experiments. The instrumentation however has broad application to both the civil and mining engineering fields and impacts on both safety of men and equipment and on direct operating costs.

2. SMART CABLE CONCEPT

If the extension or stretch ($d^{i} - d^{i+1}$) between two known locations (L^{i} and L^{i+1}) along a 7-wire strand cable can be measured, the strain (often referred to as elongation) may be written:

$$\varepsilon = \frac{d^i - d^{i+1}}{L^i - L^{i+1}} . \quad \text{(m/m)} \qquad (1)$$

For 15.8mm (0.6") diameter low relaxation 7-wire strand (ASTM A416) the corresponding tension is

$$F = k\varepsilon \text{ (kN)}, \qquad (2)$$

where for the elastic response:

$$k = 25000 \text{ kN/m/m} \quad (0 < F < 225\text{kN}) \qquad (3)$$

and for the strain hardening response after yield:

$$k = 600 \text{ kN/m/m} \quad (F > 225\text{kN} \quad \varepsilon < 0.008\text{m/m or } 0.8\%). \qquad (4)$$

Thus the average load in the cable can be calculated from the strain between adjacent anchor points, and by using multiple anchor points the load along the entire length of the cable bolt can be determined. The instrumented cables described in this paper each have six anchor points discretely tied to a potentiometric readout and employ this basic principle. The instrumented cable can be manufactured from any cable type (bulge, plain etc.) up to 30m long and can be plated if required. It will be referred to as Stretch Measurement to Assess Reinforcement Tension or *SMART* technology (Hyett *et. al.*, 1997).

3. COMPANION INSTRUMENTATION

SMART MPBX instruments behave in the same manner as any other multiple position extensometer. The advantages of the SMART MPBX are:

- very low cost for six anchor MPBX with full electrical readout, and
- the SMART MPBX readout head is only 25 mm in diameter and as such can be fully recessed into the borehole where it is fully protected from damage from equipment, etc.

The SMART contractometer is designed to act opposite to an MPBX [i.e. it measures compression of the rockmass or convergence of mined openings versus the expansion or dilation of the rockmass measured by the MPBX]. The contractometer utilizes the same SMART electronic readout head technology, allowing the instrument to be fully recessed into a borehole through a rock pillar, or built into manufactured structures such as shotcrete pillars, concrete walls, etc. Both the SMART MPBX and the SMART contractometer can be used in conjunction with SMART Cable instruments or can be used independently.

4. IMPACT OF SMART CABLE INSTRUMENTATION ON OPERATIONS BASED ON FIELD CASE STUDY DATA

SMART cable bolt instruments have two major impacts on mining operations:

1. safety, and
2. support and operational cost control.

Instrumented cable bolt support can significantly impact ground support and mine production costs in a number of ways as listed below.

- Optimization of the cable bolt array, both in terms of support density [i.e. pattern] and support length can result in a decrease in the number of cables used in an array. More significantly, cable bolts are often placed to a much greater depth than actually required since the optimum cable length is impossible to determine theoretically. SMART cable instruments indicate appropriate cable lengths for particular mining situations. In critical areas longer [and less expensive] MPBX instruments can be used to test for possible ground movement beyond the cable bolt support.
- Instrumented cables can be used to evaluate the utility of cable bolt support in critical areas such as brows and drawpoints where the rockmass is often highly relaxed, [i.e. areas where poor cable bolt performance would be expected]. Where cable performance is shown to be very poor the cable support should be abandoned in favor of alternate support techniques.
- SMART cables can be used to help evaluate the interaction of cable bolt support with other support types [e.g. shotcrete] in order to estimate the remaining capacity of the combined support system as the mining front advances. Such knowledge is then used to evaluate rehabilitation requirements for affected areas.
- SMART cables in combination with SMART MPBX's can be used to demonstrate the advantages of various cable bolt designs. For example, the optimum cable bulge spacing can

be determined by comparison testing of different configurations.

- The advantage/disadvantage of plating cable bolts can be determined by comparing results between plated and non-plated SMART cables
- SMART cables can be used in “in-stope” studies to provide protection for LHD equipment being used for remote mucking.
- Instrumented cables are extremely valuable in “in-stope” studies to help the operator with crucial decisions concerning the timing of backfill. For example, should a stope be fully cleaned or should some ore be left such that filling can be done prior to a back failure of the next stope.

The impact of instrumented cable bolt support on mine safety can be even more dramatic. The importance of this aspect tends to increase exponentially with increasing mining extraction ratio [and therefore with increasing mine induced stress] and for operations susceptible to rockburst events as discussed below.

- Increasing extraction ratios can lead to significant mine induced stress damage in the backs and walls of critical long term infrastructure [e.g. main haulage drive intersections, ramps, crusher stations, etc.], key areas where personnel are exposed. This can result in the loss of effectiveness of the primary support and the subsequent need for longer and higher capacity cable bolt support. SMART cables are critical in determining the support capacity [and hence factor of safety] for such critical infrastructure as mining advances. In potential rockburst areas it is imperative to demonstrate that gradual loading of the support due to increasing mine induced stress damage has not consumed support capacity to such a degree that the support cannot withstand additional dynamic loading due to a rockburst event.

A field case study illustrating the use of SMART cable bolts to address operational and safety concerns in a rockburst situation is given below.

5. FIELD STUDY ILLUSTRATING THE USE OF SMART INSTRUMENTATION IN ROCKBURST PRONE GROUND AT THE WILLIAMS MINE

5.1 *Introduction*

Williams Mine, located in the Hemlo region of Northwestern Ontario, is the largest underground gold mining operation in North America. Annual production is currently 2.1 million tonnes from underground and 400,000 tonnes from a surface pit operation, generating approximately 400,000 ounces of gold. The Mine lies on the south side of the east-west striking Heron Bay belt of metamorphosed Precambrian rocks. The orebody lies along the contact between the overlying metasedimentary rocks and the underlying felsic metavolcanic rocks. The entire package dips to the north at 60 to 70^0 and the horizontal ore thickness ranges from 3 to 50 m. The hanging wall rocks are fine grained, banded metasediments while the foot wall rock is quartz-eye muscovite schist or felsic quartz-eye porphyry. Foliation is well developed, parallel to the rock units with multiple jointing being present throughout the mine.

The uniformity of the orebody, with its steeply dipping orientation, lends itself well to longhole open stope mining with delayed backfill. The two main mining areas in the B Zone are Block 3 and Block 4, which are separated by a sill pillar. Block 3 has been in production since mid 1987 and the mining configuration is a chevron shape. The chevron is open to the west but is bounded on the east by Battle Mountain’s Golden Giant Mine. Block 4 is immediately below Block 3 and the mining configuration is a half chevron progressing from east to west [Figure #1]. The ore widths throughout the mine are greater on the east side of the orebody, tapering down in the central areas and widening out again to the west.

Initial indications of problems in the sill pillar began shortly after removal of the first stope under backfill in 1994 (6-9415 stope). As mining progressed several sidewall failures occurred along with the first significant back failures. In November 1996, the first major ground failure occurred, which affected the mine’s ability to produce from this area.

As mining continued the frequency of ground falls increased. In all, from November 1996 to October 1997 there were four major ground occurrences in the Block 4 sill pillar area. This delayed the mining of approximately 1,000,000 tonnes containing some 300,000 ounces and seriously hampered production from the mine. Details of the sill pillar mining at the Williams mine are given by LeBlanc and Murdoch, 2000.

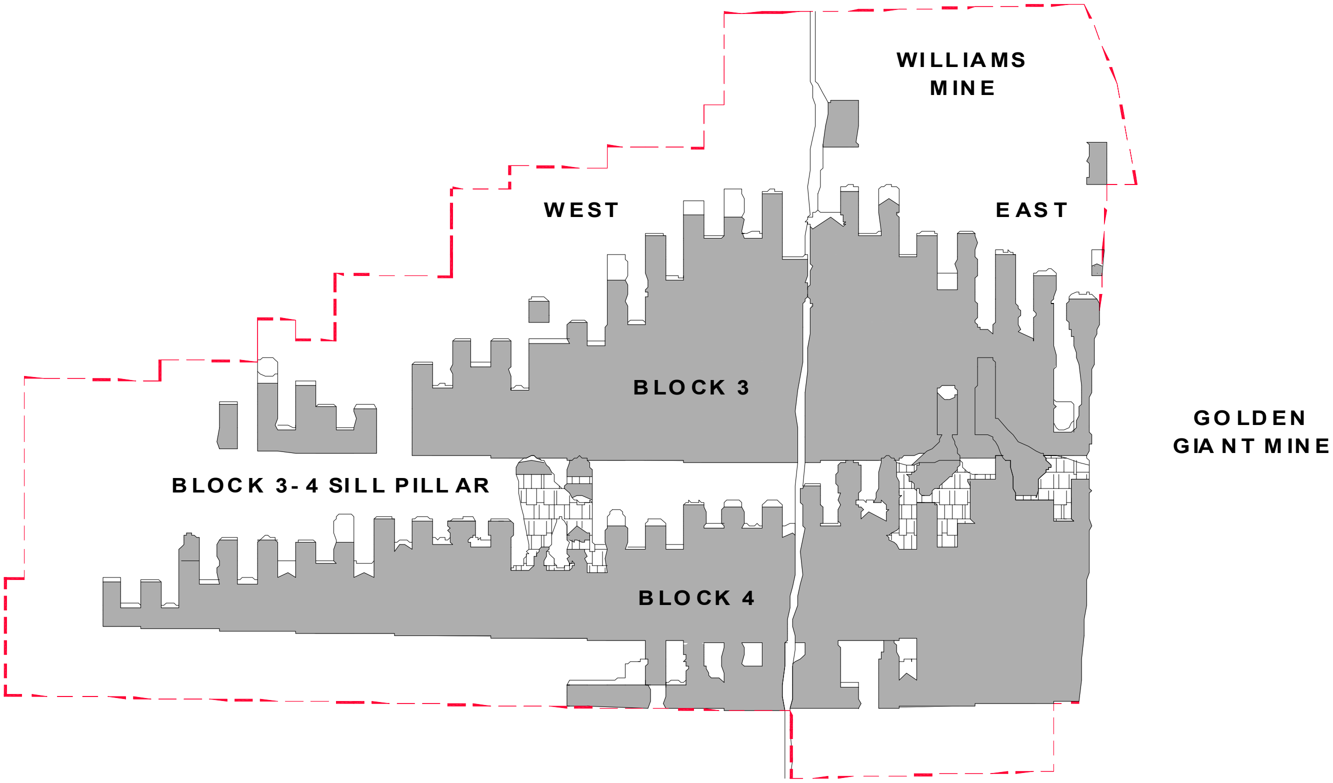

Figure 1. Longitudinal of B-Zone Looking North.
[After LeBlanc and Murdoch, 2000]

5.2 *Sill Pillar 3.0 Mn Rockburst*

On March 29, 1999 a magnitude 3.0 Nuttli rockburst occurred in the Block 4 sill pillar. The event was felt on surface and was picked up by the Geological Survey of Canada at several sites in Ontario. Previously, no event larger than an estimated 1.0 Nuttli had been experienced in the Hemlo camp. The location of the event was a major concern as until that time all ground falls and seismic activity had taken place within the ore zone. In this case, the main damage zone was located in the footwall drift, centered between 18 x/c and 26 x/c on the 9415 level, one level below the cemented sill of Block 3. Massive failures occurred in the back of the footwall drift at the cross cut intersections from 20 x/c to 26 x/c on 9415. Floor heave, buckling of the lower south wall and spalling of the upper north corner of the foot wall drift occurred on the 9450 level throughout the same area. The center of the damaged area was located in the shadow of the #3 ore pass system. Only minor damage occurred on levels above 9450 and below 9415. The only active mining ongoing in the area was 26-9370 stope, where the first lift had been blasted and removed one week earlier.

Approximately 160m of extensive rehab work was required to reopen the 9450 level. The rehab consisted of scaling and debagging loose, rebolting with 5’ resin grouted rebar on a 1.1 m x 1.1 m pattern and screening sill to sill with 6 gauge screen. A 3” layer of shotcrete was then applied from floor to floor. The drift back and south wall were then bolted with specially designed 7m cables, installed 5 to a ring on 2.5 m spacing. The cables were double 7m cables with the first 5m plain strand, to act as a “shock absorber”, and the bottom 2m having bulges to firmly anchor the cable. The cables were grouted, plated with 12” x 12” plates, to increase the effectiveness of the cable, and then tensioned to 2,500 psi. Instrumented SMART cables were installed in the footwall opposite each cross cut. The cost of the rehab on 9450 totaled approximately $500,000.

On the 9415 level, rehab costing $250,000 will be necessary to reopen the area from 17 x/c to 19 x/c but the caved area beyond 19 x/c has been abandoned. The damage was considered too extensive to rehab as the drift back had failed 4 to 5m high at the cross cut intersections. A ramp was driven from the 9370 level to the 9415 level in the vicinity of 40 x/c to re-establish access to the west

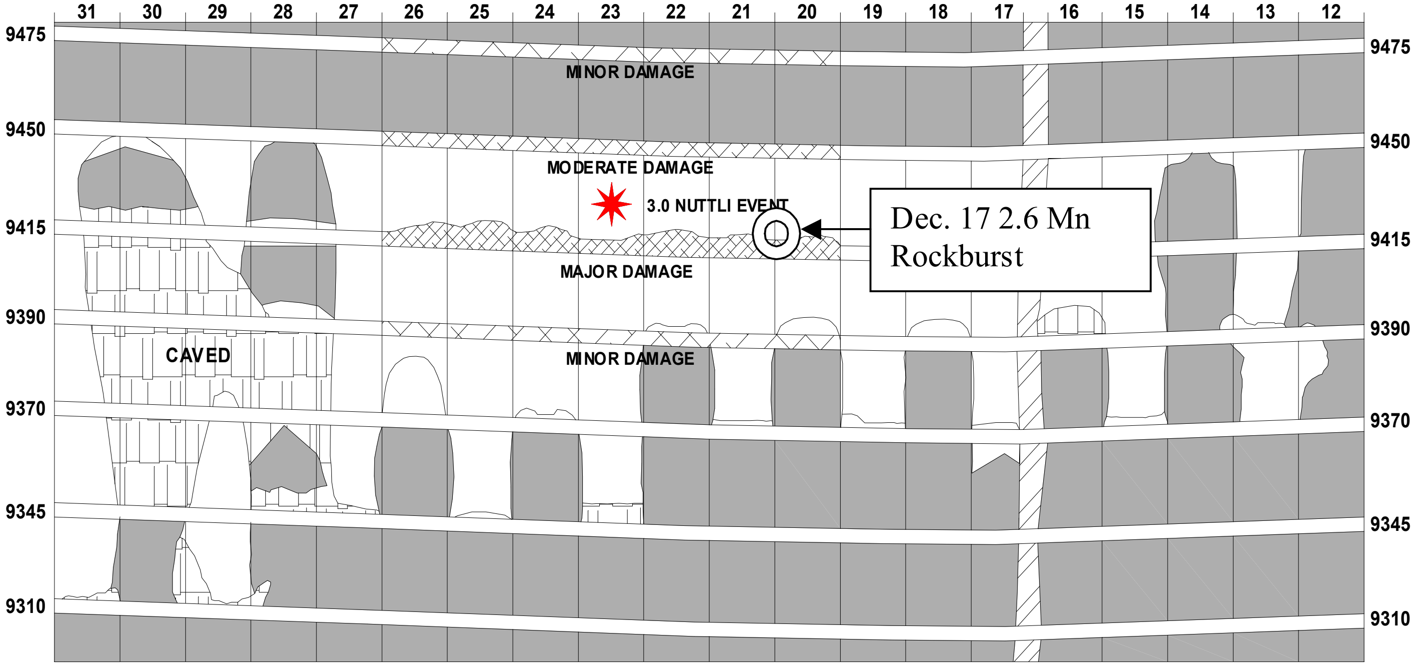

Figure 2. Longitudinal looking north of area affected by March 29th rockburst [Modified after LeBlanc and Murdoch, 2000]

end of the level. The cost was in the order of $ 1.1 million for some 535 m of ramp and access drifting. Alternative mining methods were looked at to recover the ore in the area of 20 to 27 stope. The most cost effective option, judged to have the best chance of success, was to develop a hanging wall drift through 27 x/c, drifting eastward to access the existing stope crosscuts as required. The cost of rehabbing 27 x/c, developing and supporting this hanging wall drift is expected to be $1,300,000.

The 9390 level received little damage during the rockburst; however, as the upper levels had already experienced extensive damage to the rockmass it was judged to be the area of greatest risk should another rockburst occur. A support system was designed to withstand a seismic event of similar magnitude to the 3.0 Nuttli event, which caused the extensive damage to the levels above. Minor debagging and scaling was done and the level was then rebolted, screened with 6 gauge mesh and a 3” layer of shotcrete applied. Rings of the same “soft” support cable bolts used on 9450 were installed on a 3.0 m spacing from 17 x/c to 28 x/c. Both walls, as well as the back, were cabled and the back was instrumented with SMART cables at the cross cut intersections. In addition, a yielding support of rings of 6m super swellex was installed between the rings of cable bolts. The expected cost of the rehab and support on this level, when completed, is $600,000.

Table 1 summarizes the costs of rehab, instrumentation, extra drifting and ramping required to rehab the area and resume mining in the central sill pillar due to the rockburst.

5.3 *December 17, 1999 Mn 2.6 rockburst*

Following the 3.0 Mn event a portable 8 channel microseismic system was installed around the Block 4 sill. This installation was completed in September 1999. On December 17th a rockburst of magnitude 2.6 Nuttli occurred in the sill pillar in the area of 21

TABLE 1. Costs Associated With the March 29th Rockburst [After LeBlanc and Murdoch, 2000]

Area	Cost
9450 Rehab	$500,000
9415 H/W Access Drift	$1,300,000
9390 Rehab	$600,000
9370 Rehab	$300,000

West End Ramp	$1,100,000
Microseismic Systems	$560,000
Total	$4,360,000

x/c on the 9415 level and was again picked up by the Geological Survey of Canada national seismic network.

Further caving was noted in this area, which, had been abandoned after the March 29th rockburst. Intense microseismic aftershock activity was recorded, particularly in the western sill, for the remainder of December 1999 and January 2000. The SMART cables on the 9450 level indicated local loading of the cable bolt support, but no damage occurred in any of the areas that had been rehabbed and resupported. Figure 3 shows the 9450 level plan indicating the location of SMART cable instruments, generally located in the cross cut intersections.

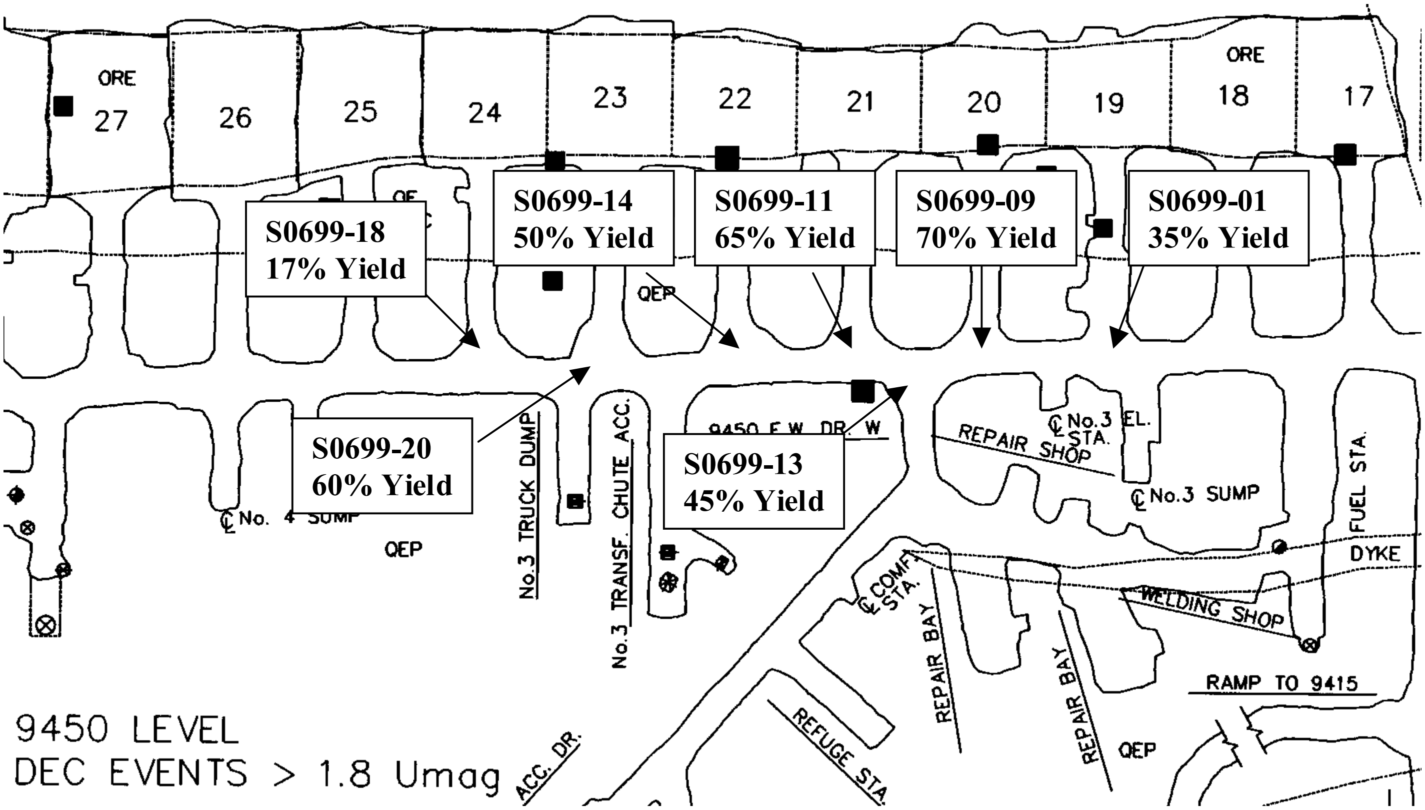

Figure 3: 9450 level plan showing SMART cable instrument locations

SMART cable instruments showed sharp load increases from the # 24 though the # 19 cross cuts. Figures 4 and 5 show typical results showing displacement versus time and load versus cable length for three of the SMART cable instruments. SMART cable results from the #24 cross cut [S0699-18], the western most cable affected by the rockburst event, shows limited impact [about 4 tonnes between 1 and 3 meters depth].

SMART cable data from the adjacent #23 cross cut [S0699-20] indicate more dramatic loading of the support has occurred. Figure 4 indicates that significant strain has occurred in the cable support between anchors at 3 and 4 and 4 and 5 meter depth. Figure 5 indicates peak loading of about 12 tonnes [60% yield] at a depth of about 3.5 meters into the back.

Data from the SMART cable in the shaft access intersection, [S0699-13, Figure 4] indicate that the major strain on the cable support occurred between anchors at 2 and 4 meter depth. Figure 5 indicates a maximum support load of about 9 tonnes [45% yield] at a depth of about 4.5 meters into the back. SMART cable data from the #19 cross cut indicate that loads had once again dropped to low levels.

Figure 3 also shows the percentage of yield indicated by the smart cables in each intersection. High cable loads were recorded between the # 20 and the # 23 cross-cuts with the maximum loading occurring at the # 20 –21 cross-cuts. At both the #19 and # 24 cross-cuts loads drop off sharply. The load versus time plots shown over indicate no movement prior to November 16th, followed by a gradual deformation between November 16th and December 17th. In reality however, the instruments had not been read between November 16th and the December 17th seismic event. It is these authors belief that no load of the cables had occurred prior to the December 17th event at which time loading occurred as step function. The 9450 level also had 75 mm of weldmesh reinforced shotcrete applied floor to floor through this area. It is interesting to note that, other than very minor local surficial spall, no damage of the shotcrete support was observed. While the 2.6 Mn events itself could not be located by the seismic system, aftershock microseismic clustering suggested that the event epicenter was located near the 9415 level. Surprisingly, no damage and no SMART cable loads were observed on the 9390 level. Following the March 1999 3.0 Mn event this level was considered at the highest seismic risk in the sill pillar. As such, an even heavier support design was applied than was used on the 9450 level. Apparently this support was sufficient to withstand dynamic loading from the 2.6 Mn seismic event. The rockburst caused additional caving in the back of the 9415 level in the east sill, but this area had been abandoned after the 3.0 Mn event and is unsupported. Subsequent to the December 17 rockburst additional cable bolt support has been placed in the affected area of the 9450 level to regain the support capacity consumed by the 2.6 Mn event. The cost of this rehabilitation however is trivial compared to the costs incurred with the 3.0 Mn event when the support in these areas was much lighter [Table 1].

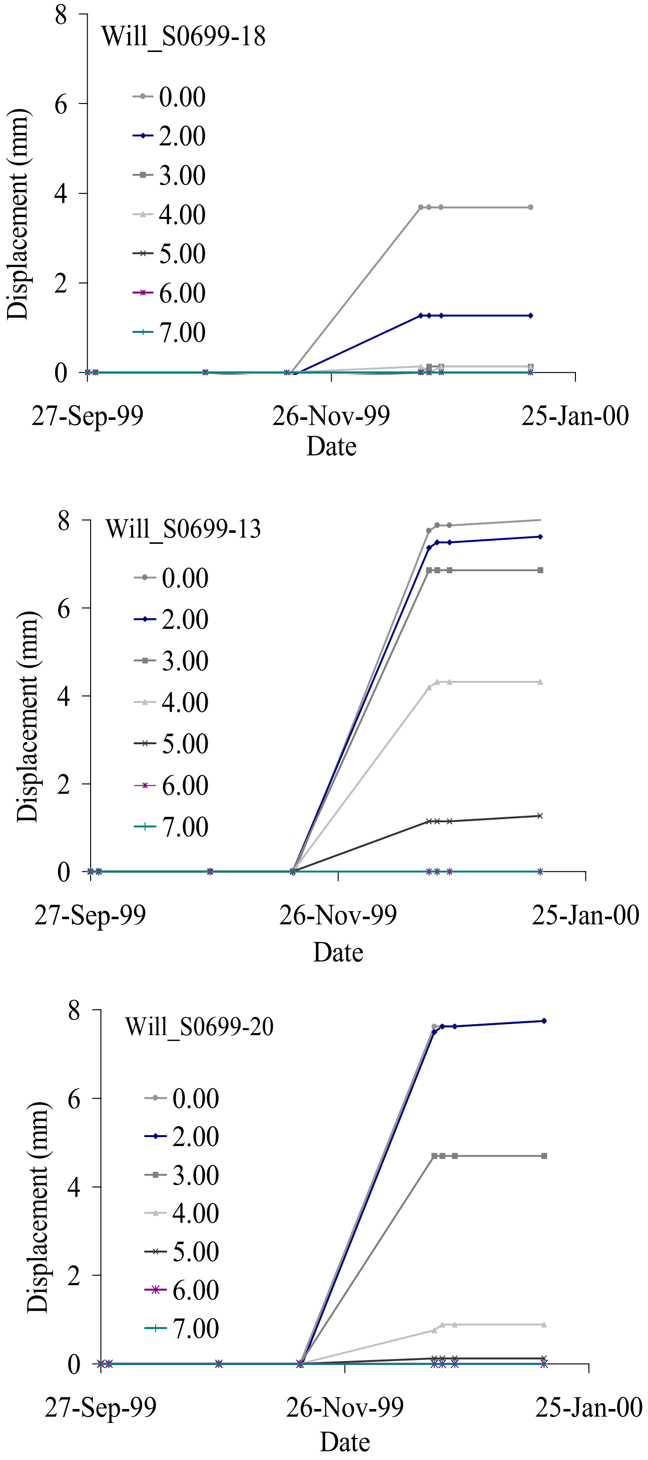

Figure 4. SMART cable results: displacement vs. time (top: S0699-18, middle: S0699-13, bottom: S0699-20)

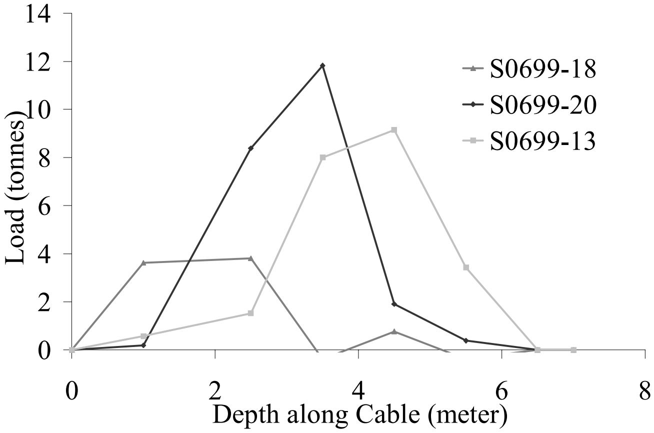

Figure 5. Load versus depth along cable after December 17th rockburst

6. CONCLUSIONS

The capability to directly instrument cable bolt support results in direct cost savings through elimination of excessive support, [i.e. array optimization and rationalization of cable lengths], and through elimination of unnecessary work functions [e.g. unnecessary plating of cables]. Instrumented cable bolt support also permits a quantified risk assessment where critical management decisions must be taken concerning, for example:

- cases where equipment is being operated remotely under open stope backs, and
- backfilling versus completing final stope clean up.

More importantly, instrumented cable bolt support allows real time assessment of remaining support capacity in critical areas, [e.g. main haulage intersections, ramps, crusher stations, etc.], where personnel and equipment are routinely exposed. Such data allows for timely and rational planning of rehabilitation programs for critical infrastructure. Finally, where rockburst events may result in instantaneous dynamic loading of ground support, often at significant depth in the rockmass, instrumented cable bolts are critical in order to evaluate post rockburst support conditions. This allows for an immediate tactical geomechanical assessment of mine support as illustrated in the case study in this paper.

7. REFERENCES

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