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CANMET STRAIN MONITOR

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ABSTRACT

The Mining Research Laboratories of CANMET, EMR have developed a new instrument which monitors with high precision the radial deformation of boreholes. The result is the CANMET strain monitor which uses the highly stable and very sensitive vibrating wire principle to monitor deformations in relatively large boreholes. Instruments are available for bore holes of 76 mm, 118 mm and 153 mm diameters.

The vibrating wire is strung across a proving ring and operates at a frequency between 600 to 1800 Hz. The resonant frequency may be determined with continuous vibration or with a plucking system.

The ring is installed with a hydraulic tool and brought into contact with the surrounding rock through precisely machined and guided wedges. The installing tool may be used to recover the instruments for calibration during long term monitoring or for use at other sites. The resolution is in the neighborhood of 4×10^{-4} mm/Hz. The data collection is carried out with a pocket size read-out unit or by automatic data logging.

The system was tested in a number of mines for the purpose of monitoring the effects of drift development and production blasting on surrounding ground stresses. Stresses are calculated from bore hole deformations.

Roctest of Montreal has obtained a license for the manufacturing and distribution rights. A patent has been registered and the Mining Research Laboratories will assist in installation of the strain monitoring system and the interpretation of records.

Case histories are reported from a mine at about 300 m depth and a hard work mine in the Canadian shield at a depth of 2000m.

INTRODUCTION

The monitoring of elastic deformation of excavation walls during mining activities has for many years suffered from the lack of suitable instrumentation reliable and sensitve enough to record the rather minute deformations in hard rock.

Based on the reliable long-term performance of vibrating wire sensors, a relatively stiff ring was developed at the Mining Research Laboratories of CANMET (Canada Centre for Mineral and Energy Technology) which is set with guided wedges in 76 to 153 mm diameter (2.98 in., 4.66 in., 6 in.) drill holes. In the following sections, the mechanical assembly of the CANMET strain ring is described with the peripheral equipment required for installation and read-out. Two case histories are reported.

CANMET STRAIN MONITORING SYSTEM

Figure 1 shows the CANMET strain monitoring system. It comprises a vibrating wire sensor and a read-out unit. The sensor consists of a steel ring which carries a vibrating wire with exciter unit to read the resonant frequency of the wire. As the steel ring is deformed and the wire in turn is either stretched or shortened, this resonant frequency changes.

Figure 1: CANMET Strain Monitoring System

Figure 2 shows a calibration curve for a vibrating wire sensor built for a 153 mm diameter (6 in.) drill hole. The 0.3 mm (0.012 in.) diameter piano wire has a length of 100 mm (4 in.). As the exciter unit and read-out system are stable to 1 Hz, deformations of 0.0004 mm (0.00001 in.) can be reliably detected. For a borehole with a 153 mm (6 in.) diameter the resolution is 0.000003 strain. The sensor is a deformation monitoring device but with suitable calibration it can be used to monitor load or stresses for specific rock materials.

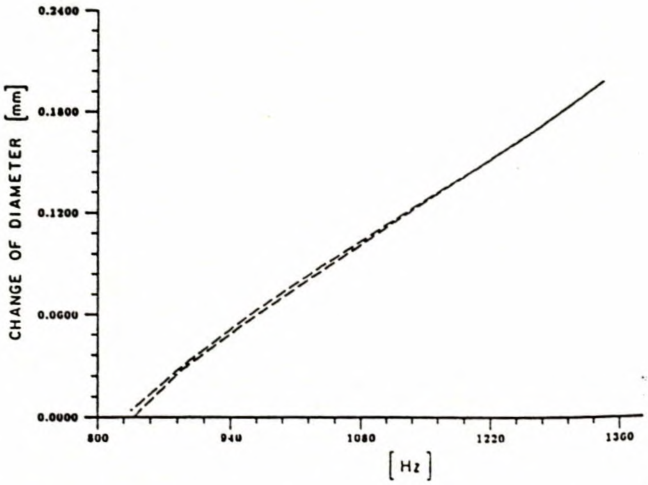

Figure 2: Calibration Curve for Strain Sensor

The vibrating wire is typically made of high strength piano wire which has to be firmly clamped into the proving ring. The clamping mechanism has to be such that clean vibrations are achieved and that no creep occurs at the clamping points. The pull on the piano wire lies typically between 5 to 15 lbs. For the CANMET strain rings a special split tube seat was developed to clamp the wire.

The dimensions of the proving ring were arrived at with a number of closed form solutions and finite element analysis. The intent was to achieve the following:

1. high contact pressures to achieve reliable readings and blast vibration resistance;
2. uniform deformation of sensor when installed, e.g. avoid twisting or misaligning;
3. ring stiffness below rock stiffness;
4. vibrating wire deformation below yield point of piano wire;
5. achieve resolution to monitor elastic deformation in hard rock, e.g. better than 0.001 mm/Hz;
6. generous dimensions to allow recovery of units after use.

The most quantitative results were obtained by finite element analysis. For an installation in a 153 mm (6 in.) diameter hole an outside diameter of 127 mm (5 in.) and an inside dameter of 89 mm (3.5 in.) was chosen. A hardened steel ring deforms by about 0.38 mm (0.015 in.) under a load of 50 KN (11240 lbs). The seating pressure is about 18 KN (4047 lbs). This changes the vibrating wire frequency by about 200 Hz. These high seating forces have been very beneficial. They achieve firm contact in the drill hole by crushing minor asperities and make the installation resistant to accelerations during blasting.

As can be seen in Figure 1, there are two groves machined into the proving ring which are located on a diameter. The grooves have a taper of about 3° which accept complimentary wedges so that during movement of the wedges along the proving ring, the outer surface of the wedges remains parallel to the borehole axis. These wedges are activated during installation by a hydraulic piston. The installing tool is described in the following chapter. High seating pressures and precise guidance for the contact wedges ensure that the rings perform on site as calibrated in the laboratory.

Table 1 below (dimensions in mm) describes the available rings:

Drill Hole Size	Ring O.D	Ring I.D	Placement Range	Resolution (mm/Hz)	Sensor Range
153	127	89	149-159	0.0004	0.38
118	99	67	116-126	0.0003	0.25
76	64	43	73-80	0.0003	0.20

These hole sizes were chosen because they are used for stress determinations or are common in structural drilling.

INSTALLATION AND RETRIEVAL SYSTEM

The installation is carried out with a hydraulic piston which activates a pushbar and in turn pushes the wedges along the grooves as the steel ring is held firmly in place by two metal arms. The metal arms are connected to the ring by countersunk flathead screws. When the required seating pressure is reached, these metal screws are sheared and the ring thus disconnects from the installing tool. The installing tool can then be retrieved. The material and the diameter of the attachment screws are chosen on the basis of the seating pressure required for the rings. Brass screws with drilled out centres have been used successfully.

The mechanical seating of the rings and their generous dimensions allow recovery of the sensors after use. For this purpose, the arms on the installing tool are equipped with a key which is pushed past the wedges of an installed ring and rotated to engage the wedges. By activating the hydraulic pressure pump, the wedges are retracted while the ring is held in place. After the wedges are loose, the ring can be pulled using the connecting lead wire. These rings can be recalibrated in the laboratory and installed at some other location. If borehole deformation has been small, a long drill steel pushed hard against the ring will drive the ring off the wedges for recovery. This will not be effective if borehole deformation has been severe.

READ OUT SYSTEM

The oscillator circuit used to vibrate the wire is enclosed within the ring. The power consumption for continuous oscillation is about 10 mA. The read-out unit records frequency and is only slightly larger than a pocket calculator (Figure 1). The exciter unit, the read-out and the signal conditioning unit for automatic data logging have been built by the Instrumentation Section of the Mining Research Laboratories.

Commercial data logging units like the Grant Squirrel 1201 (42 k storage capacity) have been used successfully to record vibrating wire sensors in mines for many weeks. A new data logger which can read four frequency channels and four thermistors has been recently built by Richard Brancker Research Ltd. of Ottawa. This unit including power supply is housed in a metal pipe 58 mm (2.25 in.) diameter and 533 mm (21 in.) long. The unit, which can be completely hidden within the borehole, is waterproof and can be left unattended for 6 months at a time. The data logger and the vibrating wire sensors have been operating in temperatures between + 50°C and - 20°C.

NIOBEC MINE

In July 1986, six rings were installed at the Niobec mine in drill holes of 153 mm diameter which had been previously used for ground stress determinations. The Niobec mine is located about 380 km NNE of Montreal, Québec. About 1500 tons of ore are produced per day from a trackless blasthole open stoping operation (Figure 3). The mine produces Niobium oxide from a carbonatite body.

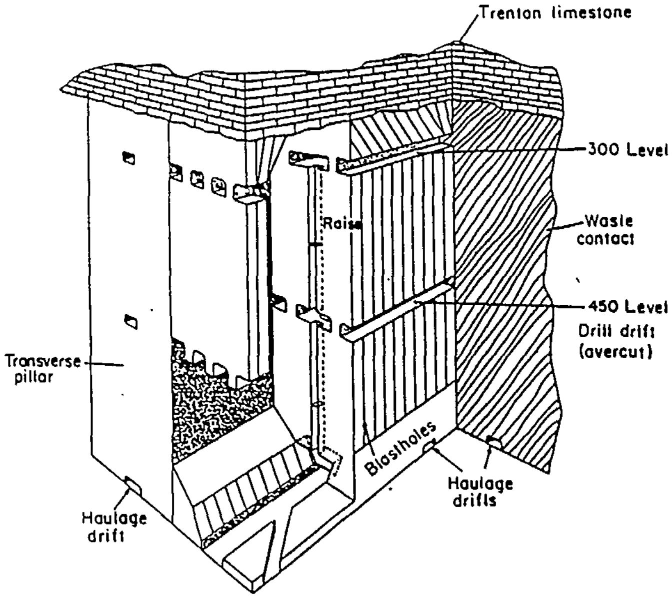

Figure 3: Blasthole Open Stoping Layout at Niobec Mine, Québec

The standard pillar width is about 25 m followed by 25 m wide stopes. Stopes are up to 60 m long from hangingwall to footwall and stope height is 100 m (Figure 4).

The instrumentation was intalled in T-213-13 pillar and in the overcut of C-203-15 stope at 850 level, in drill holes available after overcoring for stress determinations. The sites at 265m below surface and ring orientations are shown in Figure 4. The objective was to see whether stope C-203-15 would produce measurable deformations.

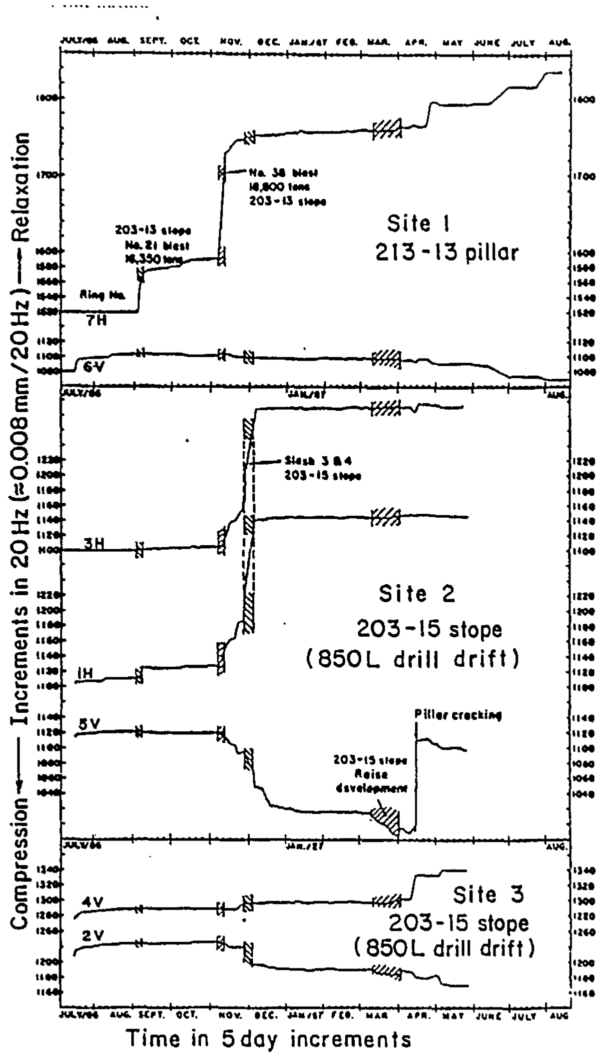

Figure 5: Response of Vibrating Wire Sensors to Blasting Activity

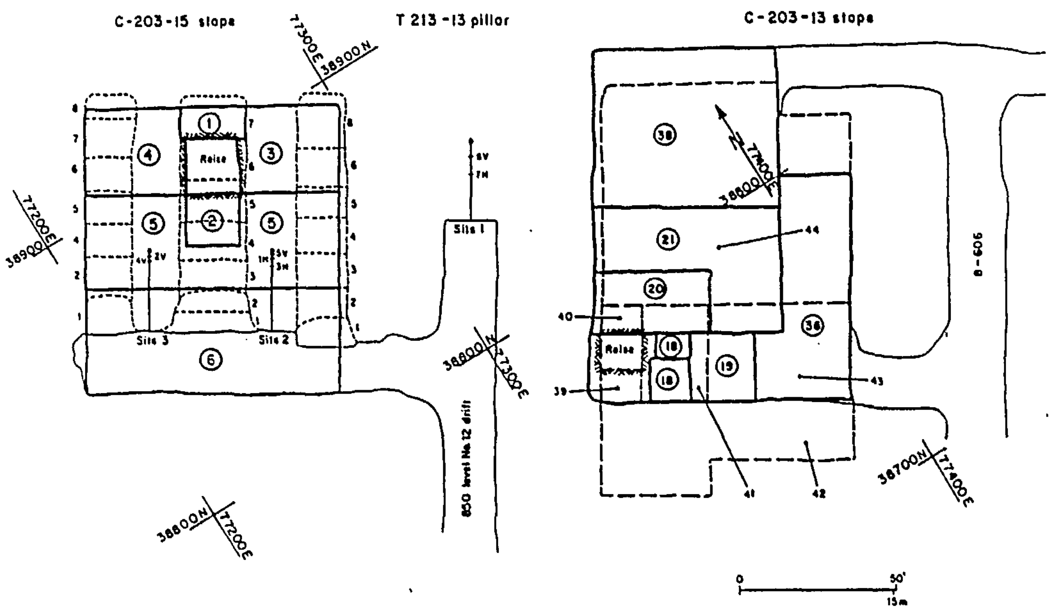

Figure 4: Blasting Sequence for C-203-15 and C-203-13 Stopes on 850 Level

Monitoring at sites 1 to 3 started on July 15, 1986 and continued until sites 2 and 3 disappeared in a production blast. The sensors were recovered before hand. Monitoring at site 1, main pillar (T-212-13), continued until March 1988.

The results are shown in Figure 5 with the major events responsible for borehole deformation. The records were of unique quality. The instruments provided consistent responses when blasting changed the excavation geometry.

REACTION OF MINE PILLAR T-213-13

The 153 mm diameter drill hole had one vertical and one horizontal ring installed. Both units operated throughout the monitoring period. The most significant response was observed between November 6 and 11, 1986. This showed an increase in the horizontal direction of 2 Hz (= 0.0008 mm) across the diameter. This was triggered by blast No. 38 involving 18800 t of ore in T-203-13 stope. This blast was opposite to the ring locations and extended from 1000 to 850 level. It indicated a loss of horizontal confinement at the monitoring site of about 10.8 MPa and 8.7 MPa based on elastic two dimensional analysis. Loading in the vertical direction was absent.

REACTION OF DRILL DRIFT PILLARS

Sites 2 and 3 were located in the overcut of C-203-15 stope. The vibrating wire sensors were installed along the pillar center line prior to the development of drill drifts on each side for use of production drilling equipment. The most severe reaction was observed between November 26 and December 5, 1986. Rings 1 and 3 which were monitoring in the horizontal direction at site 2 recorded expansions of 134 Hz (0.054 mm) and 124 Hz (= 0.05mm) respectively. The vertical reaction at site 2 was -44 Hz (= 0.018 mm) closure. Examination of blasting records identified slashes 3 and 4 in the overcut of C-203-15 stope opposite the instrumentation site as the cause (Figure 5). These records show a relaxation of 8.4 MPa in the horizontal direction and a loading of only 0.07 MPa in the vertical direction.

Site 3 sensors monitored the vertical diameter only. Ring 4 indicated no response to slashes 3 and 4 while ring 2 indicated a vertical compression of 24 Hz (= 0.01 mm). All rings monitoring the vertical direction showed little load change.

PRODUCTION BLASTING AT A DEEP HARD ROCK MINE

After overcoring for stress determinations at a depth of 2000 m in a hard rock mine in the Canadian shield, 4 sensors were installed in a 4.66 in diameter drill hole. The depth of installation was about 8 m from the excavation wall. Sensors were installed so that a diameter was measured every 45°

Table 2: Analysis of bore hole deformation with a modulus of E = 57.98 GPa and Poisson's Ratio of 0.3.

Date	Strain (10^{-6})		Max Stress (MPa)	Min Stress (MPa)	Angle of Max stress to Horizontal
881007	E_1: -5.9		0.2	-0.4	-18.7
	E_2: 3.0		0.5	-0.2	-5.7
	E_3: 4.2		0.2	-0.3	4.7
	E_4: 1.5		0.3	-0.0	-14.6
		Average	0.30±0.14	0.22±0.17	-8.58±10.4
881121	E_1: -2.3		1.5	0.3	-1.4
	E_2: 12.2		2.2	0.5	5.8
	E_3: 25.3		1.7	0.2	15.4
	E_4: 19.7		1.8	0.9	11.0
		Average	1.83±0.26	0.47±0.31	7.70±7.22
881205	E_1: -23.7		5.4	0.2	4.5
	E_2: 24.3		3.6	-0.3	-2.9
	E_3: 90.8		5.5	0.1	-8.8
	E_4: 15.2		4.8	-1.5	-1.8
		Average	4.8±0.87	-0.38±0.78	-2.25±5.45

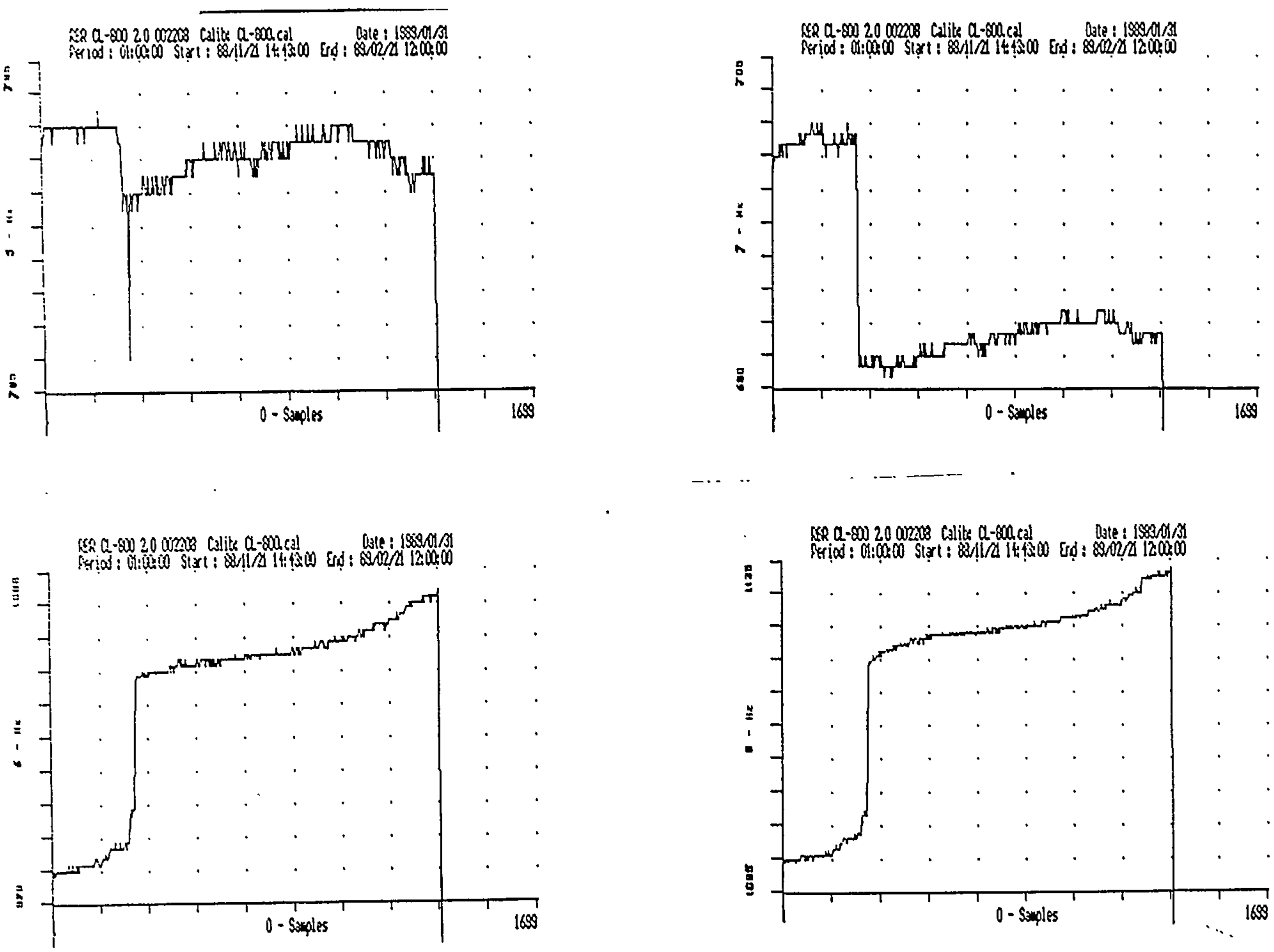

Figure 6: CANMET Strain Monitor Response after Production Blast

to obtain redundancy of measurement for the calculation of the strain ellipse. Figure 6 shows the reaction of the sensors to production blasting during the period from September 30, 1988 to January 17, 1989. Results were analysed with biaxial stress analysis and are provided in table 2.

The dates agree with major production blasts at the mine and the strains consistently increased in the horizontal direction. The one redundant diameter reading allows the calculation of the maximum and minimum secondary strains four times. The results agree very closely and indicate that the rock is still in an elastic condition. This is remarkable if one considers that the maximum principal compressive stress determined by overcoring indicated stress levels close to failure. Over the monitoring period the stresses increased by 4.8 MPa = 700 psi in horizontal direction.

STRESS CALCULATIONS

All determinded ground stress changes were based on biaxial secondary stress calculations. They do not present the absolute stress changes. For the determination of these, at least six independent determinations of borehole diameter changes are required. This requires instrumentation of three drill holes. This effort is often not made because of time and funding constraints and less than ideal monitoring layouts are applied. They will not provide absolute results but will still yield important information, such as: Is the rock still is an elastic condition? How far has the excavation effect spread? Are the stresses changing quickly and by large amounts?

ACKNOWLEDGEMENTS

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