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APRIL 1988

Published in the Proceedings 5th international (FIG) symposium on deformation measurement and 5th canadian symposium on mining surveying and rock deformation measurements 6-9 June 1988, Fredericton, New Brunswick, Canada

MINING RESEARCH LABORATORIES
DIVISIONAL REPORT MRL 88-29 (J)

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SUMMARY

The need for monitoring the effect of changes in ground stresses due to mining in hard rock has existed for many years. The Mining Research Laboratories of CANMET, EMR have developed a new tool which monitors with high precision the radial deformation in boreholes. The result is the Mining Research Laboratories strain monitoring system (MSMS) which uses the highly stable and very sensitive vibration wire principle to monitor deformations in relatively large boreholes, e.g. 100 to 153 mm diameter.

The vibrating wire is strung across a relatively large proving ring and operates at a frequency between 600 to 1800 Hz. The read-out system is based on continuous vibration.

The ring is installed with a hydraulic tool and brought into contact with the surrounding rock through precisely machined and guided wedges. The resolution of the system is in the neighborhood of 4×10^{-4} mm/Hz. The data collection can be carried out with a portable read-out unit and provisions are available for automatic data collection.

The system was tested in cooperation with the Centre de recherche minéral du Québec at the Niobec Mine in Québec for the purpose of monitoring the effects of drill drift development and stope mining on surrounding ground stresses.

After access was available to the site, 153 mm diameter holes were drilled for the determination of in-situ ground stresses. These holes were then used to install the strain monitoring system. The effect of drill drift development and production blasting in stopes C-203-13 and C-203-15 on ground stress distribution could be observed clearly.

The horizontal relaxation in the core of a pillar which occured during mining of adjacent rooms was between 0.082 mm to 0.111 mm. Calculations of streses from these deformations indicate that the rock material is still in an elastic condition.

Roctest of Montreal has obtained a license on the manufacturing and distribution rights. A patent has been registered and CANMET will assist in installation of the MRL strain monitoring system and the interpretation of records.

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 sensitive 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, which is set with wedges in 100 to 153 mm diameter drill holes. In the following sections, the mechanical assembly of the MRL strain ring is described with the peripheral equipment required for installation and read-out. The performance of the equipment in an underground mine is reported briefly.

MRL STRAIN MONITORING SYSTEM

Figure 1 shows the MRL 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 resonnant frequency of the wire. As the steel ring is deformed and the wire in turn is either stretched or shortened, this resonnant frequency changes.

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.

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 MRL strain rings a mechanical clamping procedure has been used.

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 properties 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 diameter 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 in the drill hole wall and make the installation resistant to high blast acceleration forces.

As can be seen in Figure 1, there are two grooves 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 an installing tool which 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.

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. In many cases brass screws have been used successfully.

The method of mechanical seating the rings and their large dimensions allows recovery of the vibrating wire sensors after use. For this purpose, the arms on the installing tool are equipped with a key for connection to the wedges of an installed ring. 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. A simpler method of recovery involves use of a long drill steel which is pushed hard against the ring. This will drive the ring off the wedges.

READ OUT SYSTEM

The oscillater 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). Commercial data logging units like the Grant Squirrel 1201 (42 k storage capacity) have been used successfully to record readings at Inco's Creighton mine for many weeks.

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.

A new data logger which can read four frequency channels 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 can be completely contained within the borehole being used, is waterproof and can be left unattended for 6 months at a time.

FIELD EXPERIENCE

Many things work well in the laboratory but reveal many weaknesses when used in the rugged environment such as a construction or mining site.

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 Montréal, 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.

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, about 265 m below surface. The sites and ring orientation are shown in Figure 4. The objective was to see whether blasting in stope C-203-13 and development of the rooms in the overcut of stope C-203-15 would produce measurable deformations.

Monitoring at sites 1 to 3 started on July 15, 1986 and continued until the sites 2 and 3 disappeared in a production blast. However, rings were recovered before hand. Monitoring at site 1 continued until March 1988 in the main pillar (T-213-13).

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. This paper is not intended to interpret the ground deformations but a few highlights are given below.

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, 1988. This showed in horizontal direction an increase of 148 Hz = 0.053 mm and in vertical direction an increase 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 in the vertical direction. Loading in vertical direction was thus 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) compression. 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 only vertical deflection. 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 thus showed either little load change or relaxation as mining progressed.

DISCUSSION

The field data obtained by the new instruments were of exceptional quality. Calculations of deformation across the borehole diameter indicated that values were well within the elastic range. Relaxation in the horizontal direction was immediate and corresponded directly to the loss of confinement. It was surprising that there was often an immediate loss of loading in the vertical direction as mining progressed. This is contrary to the load increase expected to occur in vertical direction, when horizontal confinement is lost. It is possible that vertical loads were transferred to areas of the mine outside the section being monitored.

ACKNOWLEDGEMENTS

This study was part of a rock mechanics research project carried out in connection with the Centre de recherches minérales and Niobec mine. The authors appreciate very much the good cooperation with Niobec staff and the effort which was put into the conscientious recording of field readings and mining activity. Without this effort, this data base would not exist today.

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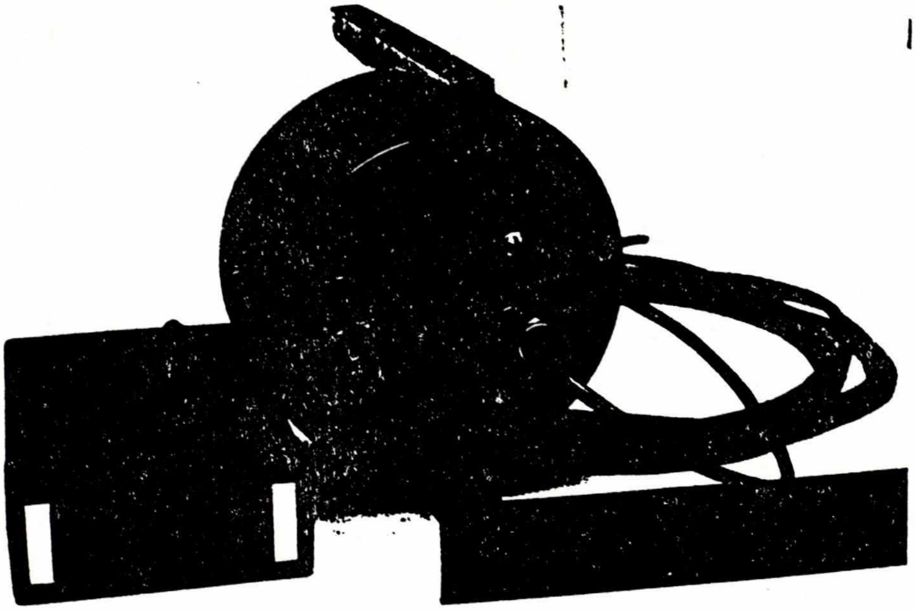

Figure 1: MRL Strain Monitoring System

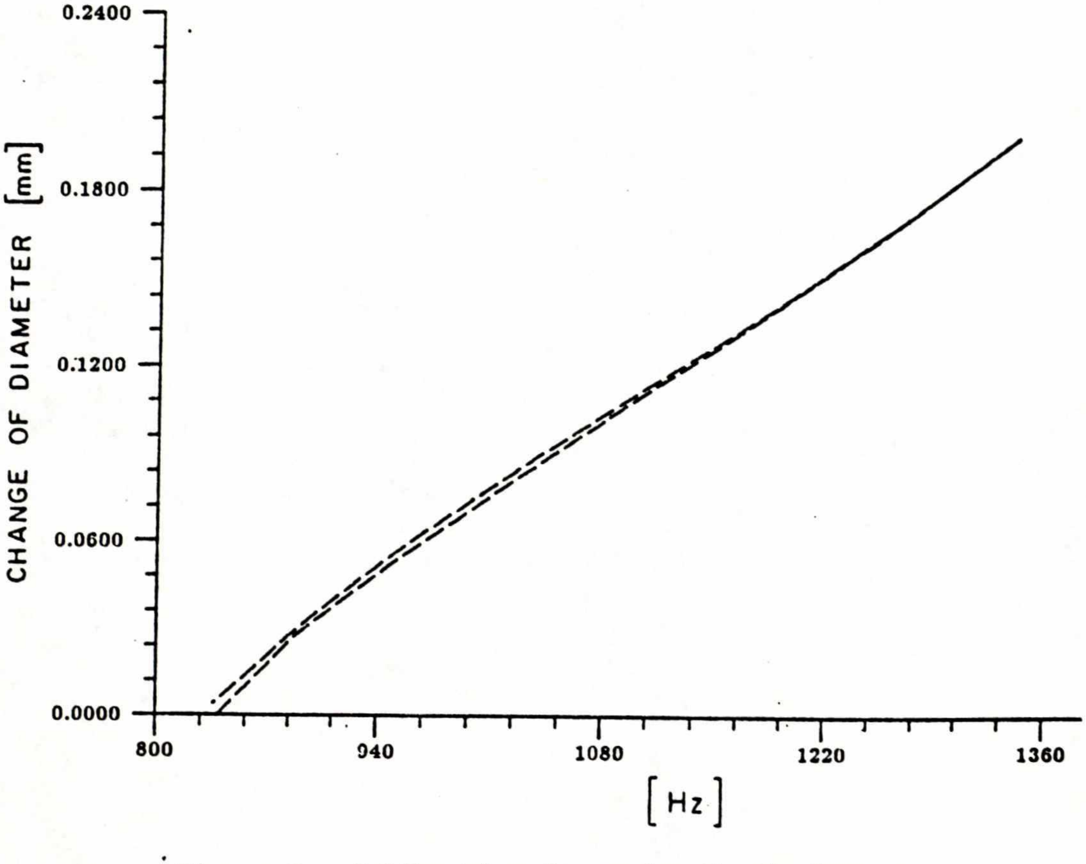

Figure 2: Calibration Curve for Strain Sensor

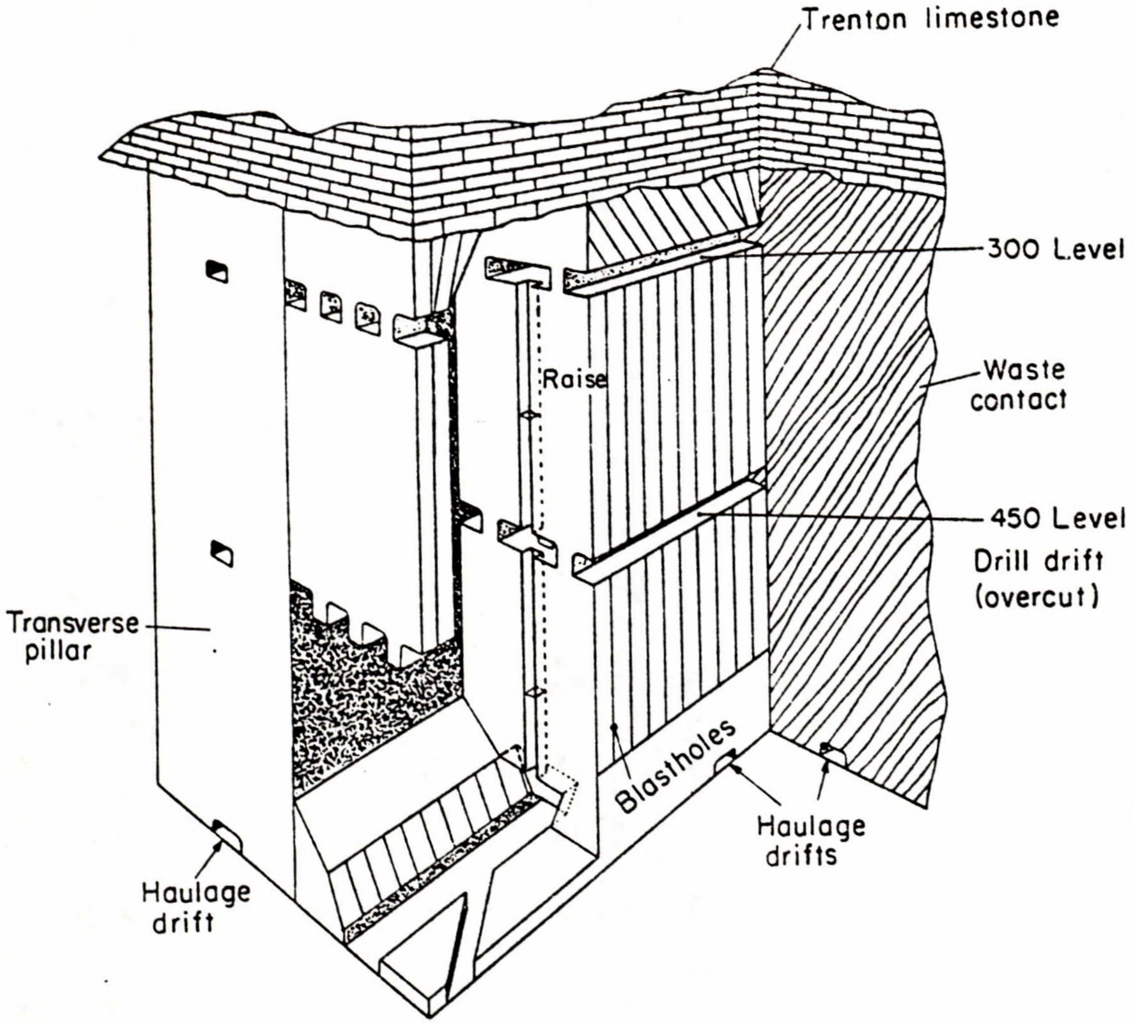

Figure 3: Blasthole Open Stoping Layout at Niobec Mine, Québec

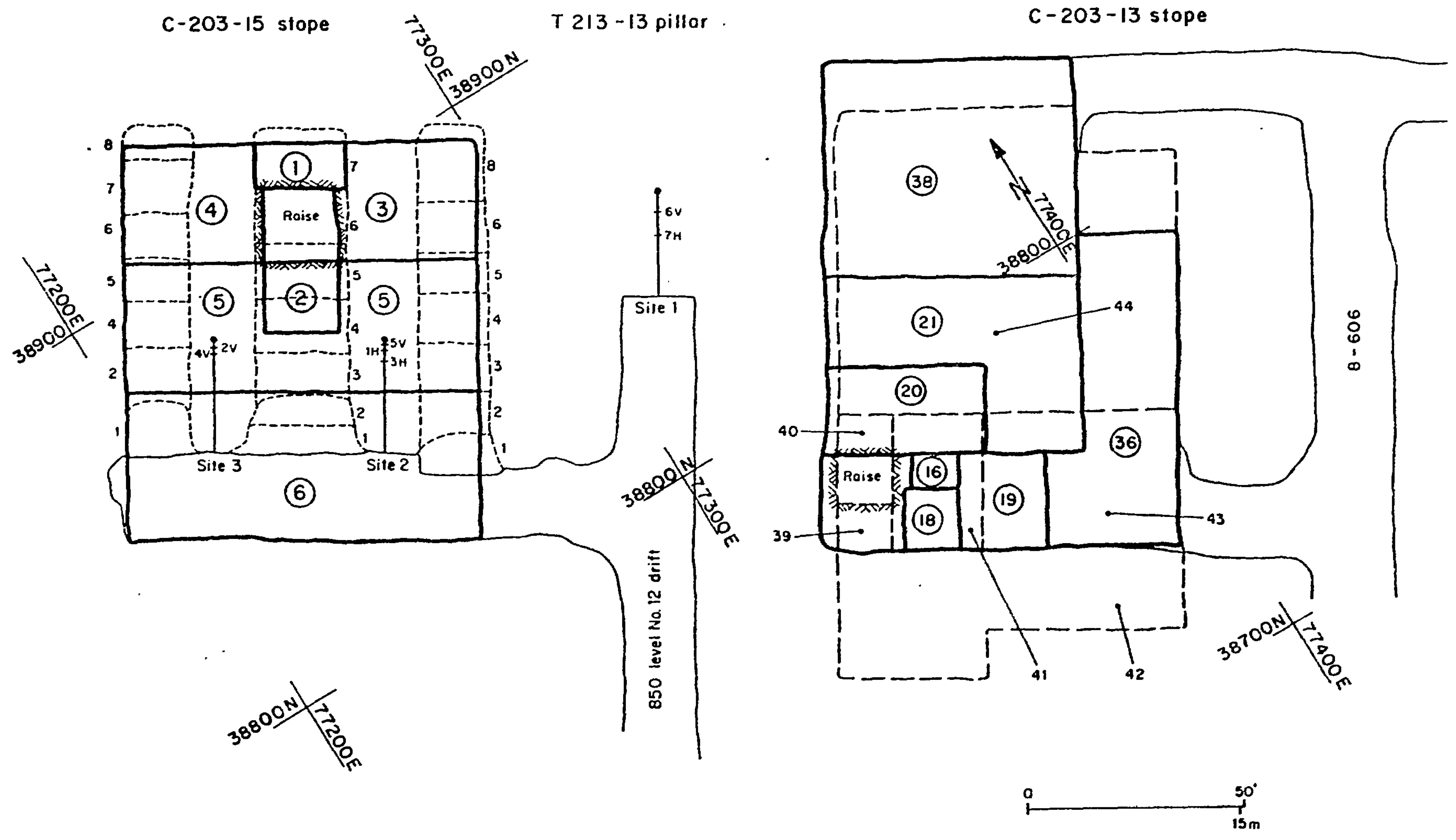

Figure 4: Blasting Sequence for C-203-15 and C-203-13 Stopes on 850 Level

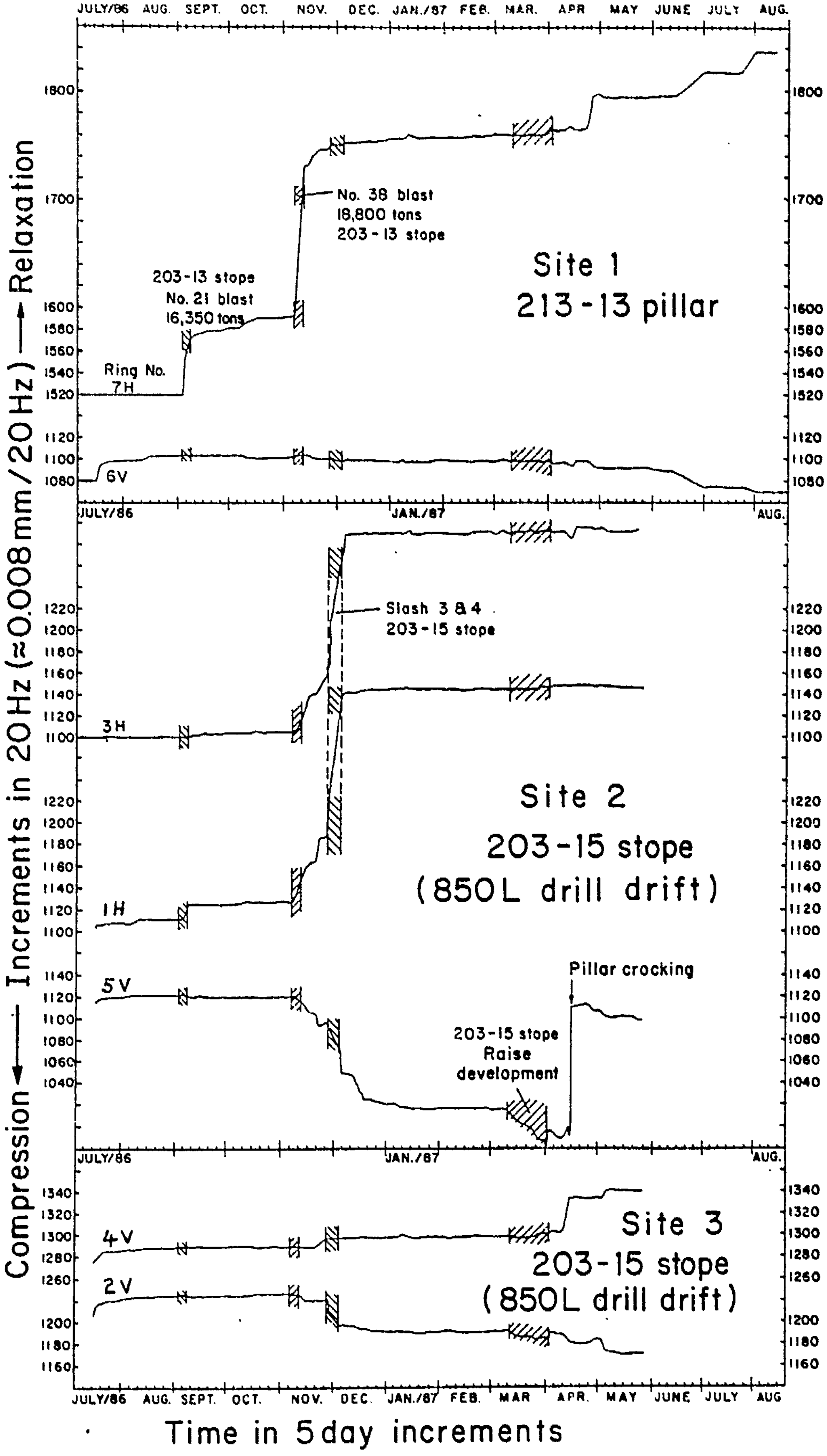

Figure 5: Response of Vibrating Wire Sensors to Blasting Activity