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Use of a miniaturized data-logger for determining the state of stress induced in abandoned pillars

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Abstract. The measurement of the natural and/or induced stress state in rock masses excavations is generally carried out thanks to techniques able of providing results both in the two-dimensional (2D) and in the three-dimensional (3D) environment, coded in the "Suggested Method" of the ISRM. The stress relief method is one of the most consolidated measurement methods, based on the differences in strain intensity evaluated in selected directions before and after making a continuous notch around the sensors involved in the measurement. With a special miniaturized data-logger applied to the sensors used for the evaluation of the rock stress in a 2D (doorstopper) or 3D (HI cell, CSIRO) environment, the execution of the measurement on site can be considerably simplified, and the complete strain-time diagram acquired due to over-coring can be obtained. The paper presents an example of measurement of the state of stress induced in some abandoned pillars in an underground quarry.

1. Introduction

The evaluation of the state of natural and/or induced stress of rock masses is one of the most demanding problems that must be faced during the design and realization of excavations for civil and/or industrial purposes.

In the last twenty years, despite the amount of measurement techniques available, a growing attention has been focused on "stress relief method". This method involves the rigid connection of a sensor to a free surface of the rock volume of which the state of stress is to be determined, and the execution of a preliminary measurement of a physical quantity detected by the sensor, called "zero" measurement. The procedure therefore provides the execution of a continuous notch around the sensor, with a minimum depth of about two times the largest size of the sensor itself. The difference between the final displacement recorded by the sensor after the "stress relief" and the "zero" measurement, indicates the effect of the stresses around the on-site rock core examined. The International Society of Rock Mechanics, in the Part II of its Suggested Method [1], indicates the "doorstopper strain cell" developed at the Council for Scientific and Industrial Research (CSIR) [2] and the "drill hole deformation gauge" developed at the United States Bureau of Mines (USBM) [3], as the most widely used instruments for determining the plane stress state (2D). Similarly, the I.S.R.M. indicates the CSIR 3D gauge, the "Hollow Inclusion cell" developed in the laboratories of the Commonwealth Scientific and Industrial Research Organization (CSIRO) [4] and the Borre probe studied at the Division of Land and Water Resources Engineering of the Royal Institute of Technology (KTH) of Stockholm [5], as the most widely

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used instruments for the determination of the complete state of stress (3D), using a single borehole. In this work, reference is only made to the relief-method based on the instrument called HI cell or CSIRO gauge, and on its modification made at the Laboratory of Rock Mechanics of the Institute of Geosciences and Georesources of the National Research Council (IGG-CNR) of Turin, Italy.

2. The method of measurement

The determination of the state of natural and/or induced stress acting into a bedrock with the over-coring method called HI cell [6] [7], first requires to drill a hole with a nominal diameter of 110 mm ÷ 160 mm and with a depth able to reach the measuring point. Then proceed, inside at the first hole and coaxially to it, to make a further hole with a nominal diameter of 38 mm ÷ 39 mm (pilot hole), with a length of about 400 mm ÷ 500 mm. After drying the pilot hole and visually inspecting the walls of the same (with a specific borescope), the instrument is made integral with its wall using a suitable glue. The measuring instrument (HI cell) is an epoxy resin cylinder equipped with 12 electrical strain gauges arranged along the center line of its circumference (figure 1a, b). To minimize the influence of the length of the multipolar cable that connects the HI cell to the measurement control unit used (normally consisting of a Wheatstone bridge), the so-called "three-wire" wiring diagram is generally used.

Once the time necessary for the polymerization of the epoxy resin used for gluing the HI cell has elapsed, the “zero” measurement for each individual strain gauge is carried out with a strain gauge measurement control unit. The experimental test starts with overcoring the HI cell installation hole with a steps of about 50 mm, that are made with the larger diameter core barrel. At each step of advancement and interrupted advancement, the "reading" of all the HI cell’s strain gauges is carried out in order to build the table of the displacements detected by each strain gauge, according to the advance of the overcoring and the time taken. The overcoring procedure ends when the advancement of the core barrel has traveled the length of 400 mm ÷ 500 mm. Then, the recovery of the cylinder obtained from overcoring can be done, after having torn its bottom end from the surrounding rock. The operations described are normally affected by "disturbances" of different intensity, the main ones being the “electrical” ones, essentially due both to the humid environment where the experimental determinations are normally carried out, and to the influence of the connection of the long multipolar cable that conducts the electrical signal from the single strain gauge to the control unit measurement, crossing the whole extension of the drill rods and the drilling rig used.

(a) (b)

Figure 1. (a) photo illustration of a Hollow Inclusion cell (HI cell) with the prominent four electrical strain gauge oriented in different directions. Some electrical connections between the individual strain gauges and the multipolar cable connecting the strain gauges and the Wheatstone bridge generally used for carrying out the measurements are also visible; (b) schematic representation of the distribution of strain gauge sensors along the median section of the HI cell’s circumference.

In order to minimize the influence of the two negative aspects described above, in 2005 a miniaturized data-logger, called *micro13,* was designed and built at the IGAG-CNR Laboratory of Rock Mechanics, Turin. That instrument is able to remotely perform and store in a special static memory, at a frequency of 15 Hz, the experimental determinations performed from the 12 strain gauges constituting the HI cell during the overcoring [8]. In 2015, a new miniaturized data-logger, called *micro12,* was developed and tested in the same laboratory, with improved functional characteristics compared to the previous one and able to be connected directly to the HI cell at its end, where the cables of the electrical strain gauges come out of the resin (figure 2)

Figure 2. Picture showing the connection between the *micro12* measuring device and a generic Hi cell. The rechargeable batteries that energize the whole system are also visible.

3. Micro12

The *micro12* is a data acquisition device operating automatically, capable of sampling and storing 12 strain gauge signals in addition to the temperature, with a frequency of 1 Hz, for over 4 hours. A block diagram that highlights the main functions implemented in the device is shown below (figure 3).

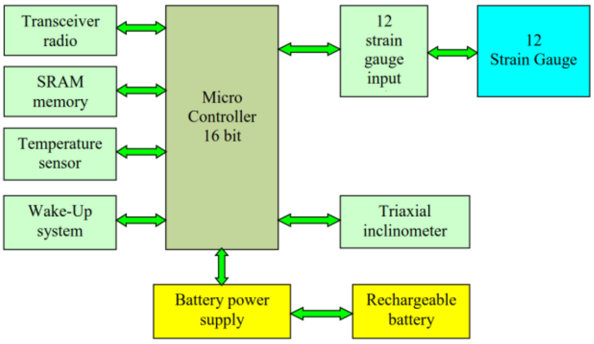

Figure 3. Schematic representation of the main functional "blocks", implemented in the miniaturized measuring device *micro12*.

The heart of the *micro12* is made by the 16-bit PIC-24FJ128GA204 microcontroller, equipped with specially developed firmware, able to manage the operations necessary for the operation of the automatic logger with XLP technology, i.e. able to carry out the required measurement operations with extremely low energy consumption. The communication interface of the acquirer is managed by a radio transceiver, capable of establishing a two-way communication, at a frequency of 434 MHz, with a transmission power of 14 dBm. The sensitivity of the integrated receiver is higher than -110 dBm, thus able to reach the communication distance of over 20 m in free air, between the automatic acquirer and the reception system connected to the PC. The *micro12* is equipped with a non-volatile memory with a capacity of 4 Mbit which allows the continuous storage of the acquired data for about 4.5 hours, with a 2 Hz frequency. The wake-up system is achieved by means of a circuit that manages a switch capable of detecting the presence of a magnetic field. By placing a simple magnet close to the switch, the start-up process of the microcontroller is activated, which in turn starts the radio-transceiver in order to receive any commands given by the user through a specifically developed software interface (figure 4). If the device does not receive commands from the user through the radio interface in an interval of 60 s from the microcontroller awakening, the device is automatically deactivated in order to reduce the energy consumption to about 5μA/h. The conversion of strain gauge signals (analog) is managed by a 24-bit Analog/Digital (A/D) converter, equipped with a variable gain amplifier with very low noise which, in case of 350 ohm measuring strain gauges, allows the resolutions lower than 0.1 με. The *micro12* is also equipped with a three-axis inclinometer in *mems* technology capable of evaluating, in addition to the vertical, the spatial position of the device in terms of pitch and roll. The device is powered by two rechargeable lithium-ion batteries with a total capacity of 420 mAh, that can guarantee, as pointed out before, a measurement autonomy of over 4 hours. Finally, the device also has the circuit necessary for recharging and balancing the charge of the batteries.

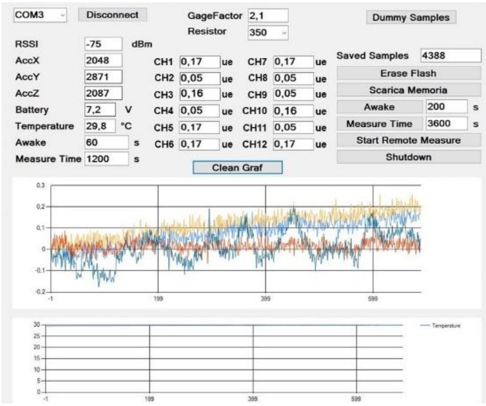

Figure 4. Data entry form of *micro12* data-logger.

3.1. *Operation of the device on site*

Once made the stable connection between the *micro12* and the HI cell with the connector or welding and having sealed the measuring device inside a carbon fiber tube of suitable dimensions, the scheduled measurements can start. In fact, when the batteries are powered, the *micro12* is always standby, or "waiting for awakening".

When the on-site stress state has to be evaluated [9], after the resin polymerization phase, thanks to which the HI cell equipped with *micro12* is made integral with the pilot hole, two time intervals must be estimated: the first is the time necessary to start the over-coring operation T_w (time required to clear the hole from the installation rods of the measuring device + time required for the core barrel and the rods battery to reach the larger diameter bottom-hole); the second, T_0, is necessary to carry out the overcoring for the whole length (400 mm ÷ 500 mm) + an extension of variable size, adopted to minimize the effect of any unexpected events. When the core containing the HI cell connected to the *micro12* has been recovered and the time T_0 has elapsed, the device is activated again and the data acquired are transferred to the PC. To find the elastic constants of the rock, that are necessary for the subsequent calculations as shown by the relative practice, both the circumferential press [10] and the axial compression tests [11] can be used, continuing with the *micro12* as a data-logger (figure 5a, b).

In the case study examined below, a double core barrel with an inner diameter of 125 mm and external diameter of 130 mm was adopted to perform the holes up to the measurement depth. Those diameters have been chosen to obtain in the laboratory, from the cores recovered before reaching the measurement point, samples of NX diameter, both in the axial and in the transverse direction of the coring. table 1 collects the average values of the pseudo-elastic constants of the rock, obtained through the laboratory tests carried out on both the NX diameter specimens, and on the overcoring cores containing the HI cells, without taking into account their orientation, but only the pillar from which they were taken (figure 6a, b). The values of the K constants calculated for each pillar are also shown in the same table, assuming, for the HI cell, the dimensions of inner radius = 16 mm; external radius = 19.05 mm and radius of gauges = 17.5 mm.

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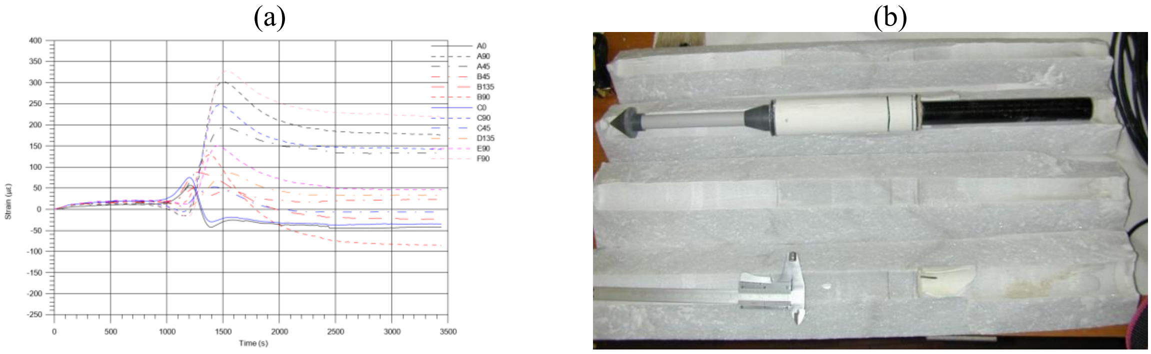

Figure 5. (a) strain - time graph obtained from overcoring of a HI cell equipped with the *micro12*. Both the time required for the diamond drilling crown to reach the point of application of the strain gauges in the HI cell, and the time elapsed from the end of the measurement to the end of the data acquisition can be noticed; (b) longitudinal section of a core containing, in the pilot hole, a HI cell connected to a *micro12*, inserted and sealed in a carbon fiber tube.

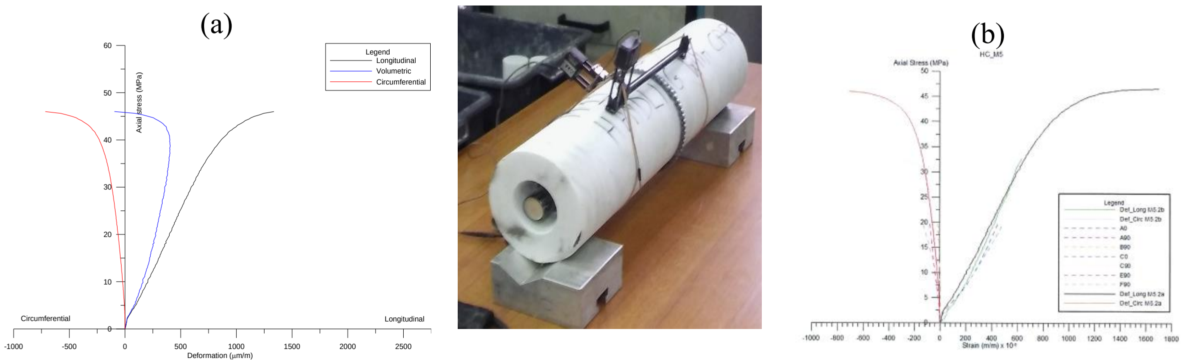

Figure 6. (a) result of an axial compression test carried out on a specimen of NX diameter; (b) result of an axial compression test performed on a core containing the HI cell connected to the *micro12*. In the relative graph, the dashed lines represent the data acquisitions performed by the *micro12*. The external longitudinal and transverse strain gauges necessary for the axial compression test, as well as the terminal part of the *micro12* still inside the pilot hole, are visible in the hollow rock cylinder.

Table 1. Average of the pseudo-elastic constants of the rock, obtained in the laboratory through the experimental tests carried out on both the NX diameter specimens and on the overcoring cores containing the HI cells, not taking into account their orientation but only the originary pillar. Are also reported the four K-factors that relate strain on the walls of a borehole to the strain at the locations of the strain gauges, calculated assuming: E_{HI} = 2647.68 MPa; ν_{HI} = 0.4 (-).

	Rock property			K-Factor			
Borehole	E [MPa]	μ [-]	G [MPa]	K1	K2	K3	K4
M1	36059	0.23	14600	1.10951	1.09958	1.06465	0.91086
M3	40209	0.26	16000	1.10975	1.10488	1.06561	0.93405
M6	25379	0.25	10150	1.09943	1.08042	1.05947	0.93372
M7	38516	0.13	17000	1.11740	1.10174	1.06630	0.74280
M8	34380	0.28	13430	1.10523	1.09809	1.06358	0.94921
M10	46279	0.28	17800	1.11098	1.11074	1.06688	0.94644
M11	29009	0.21	12000	1.10580	1.08790	1.06205	0.89550
M14	55000	0.31	21000	1.11178	1.11702	1.06821	0.96295

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4. On-site measurements

In order to verify the correct on site operation of the new device and to evaluate the advantages that it involves compared to the classic HI cell, in the center line of the abandoned pillars in an underground marble quarry were designed and carried out 8 stress state tests with the over-coring of HI cells equipped with micro12.

The quarry exploitation is essentially developed underground, in rooms with abandoned pillars, exploited with horizontal descending slices, by using chain cutters for primary cuts at the benches and diamond wire saws for squaring the blocks. The underground quarry is characterized by large irregularly shaped voids surrounded by supporting elements (pillars, diaphragms), some of whom reaching heights up to 60 m, where the excavation work takes place.

As hypothesized, the experimental tests carried out with HI cell equipped with *micro12* allowed to considerably reduce both the execution times of the measurements and to quickly verify the goodness of the measurement itself on site, by examining the continuous strain - time trace provided by the *micro12*. Operating with a single probe, considering the average length of the holes of 10 m, assuming the average distance of the measuring bases of about 30 m and adopting two different polymerization times of the glue used (one for the half-day measurement and one for the night), all experimental tests required 5 days, without any repetition. The data relating to the 8 experimental tests carried out are given in table 2.

Table 2. Stress release intensity relative to each single strain gauge of the HI cells used in the 8 pillars examined. The table shows the identification of the pillar examined the directions of the drill holes and the number of the measures. The length variations of the HI cell strain gauges are expressed in με (m/m x10^{-6}).

micro12 input channel	HI cell strain gage	α [°]	β [°]	Pillar 4 *274/5* **M1** [με]	Pillar 3 *270/5* **M3** [με]	Pillar 11 *88/5* **M6** [με]	Pillar 5 *272/5* **M7** [με]	Pillar 8 *170/5* **M8** [με]	Pillar 7 *80/5* **M10** [με]	Pillar 6 *259/5* **M11** [με]	Pillar 9 *79/5* **M14** [με]
CH1	A_{0}	323	0	495.20	265.75	259.50	346.80	59.10	233.70	262.30	321.10
CH2	A_{90}	300	90	419.80	44.75	264.10	331.20	157.80	266.30	147.90	206.80
CH3	A_{45}	300	45	491.00	216.20	232.90	331.40	118.60	19.80	266.40	91.50
CH4	B_{45}	163.5	45	427.50	234.60	227.20	329.60	141.40	297.50	215.30	274.40
CH5	B_{135}	163.5	135	377.30	263.70	193.90	192.50	174.60	130.00	133.20	0.00
CH6	B_{90}	180	90	482.00	198.40	209.10	186.00	201.10	155.00	32.20	25.90
CH7	C_{0}	83	0	418.20	279.55	252.20	327.80	62.00	248.30	303.70	186.10
CH8	C_{90}	60	90	468.00	156.10	242.30	214.00	205.90	216.70	116.10	10.20
CH9	C_{45}	60	45	367.80	133.15	223.20	176.70	156.80	452.40	65.70	160.00
CH10	D_{135}	323	0	371.00	113.30	241.40	301.20	113.00	501.70	160.00	436.50
CH11	E_{90}	300	90	477.50	208.15	227.00	266.00	58.30	151.80	122.60	59.60
CH12	F_{90}	300	45	425.00	266.20	266.10	234.40	227.20	255.70	150.70	45.50

5. Data interpretation

The data interpretation was performed by assuming two different behaviors of the material under study: linear, elastic, isotropic [12] and linear, elastic, transversely isotropic [13]. In the first hypothesis, two different calculation codes were used: StressOut and BM2000; in the second case, only the BM2000 calculation code was used. The StressOut [14] and BM2000 [15] [16] calculation codes were developed through the ForTran90 language [17] by using the Microsoft IMSL libraries.

Table 3 shows the results of the analyzes carried out assuming that the rock has a linear, elastic, isotropic behavior, in terms of maximum principal stresses and their directions. figures 7a, b, through stereographic projections, show three of the results obtained under the first hypothesis assumed. Although the interpretation of the data was made through two calculation codes based on different theoretical assumptions, the results obtained are in a good agreement, both in terms of principal stresses and of their directions.

Table 3. Maximum principal stresses and their directions obtained from the processing of "stress relief" data by overcoring of 8 HI cells made integral with the pilot holes drilled in the centerline of as many abandoned pillars in an underground quarry. Beta is the angle of bearing positive clockwise from north and Delta is the angle of inclination positive up from horizontal. The interpretation of the data was carried out according to a hypothesis of a linear, elastic, isotropic behavior of the rock, thanks to the StressOut and BM2000 software.

		BM2000 Isotropic solution			StressOut			Differences			
		[MPa]	Delta [°]	Beta [°]	[MPa]	Delta [°]	Beta [°]	Δσ [MPa]	% Δσ	Δ Delta [°]	Δ Beta [°]
	σ1	18.70	-14.64	89.99	20.41	-16.20	90.40	-1.71	9.12%	1.56	-0.41
M1	σ2	9.41	-26.15	356.55	9.38	-43.75	352.10	0.03	0.34%	17.60	4.45
	σ3	8.79	-72.56	206.40	8.83	-59.10	195.20	-0.04	0.43%	-13.46	11.20
	σ1	13.50	-17.15	89.71	13.46	-16.60	88.40	0.04	0.33%	-0.55	1.31
M3	σ2	4.78	-28.21	354.96	4.88	-21.44	355.10	-0.10	2.09%	-6.78	-0.14
	σ3	2.82	-70.47	207.49	2.88	-74.62	213.80	-0.06	2.27%	4.15	-6.31
	σ1	7.94	-6.86	264.51	7.98	-8.25	265.40	-0.04	0.54%	1.39	-0.89
M6	σ2	3.79	-80.33	15.81	3.74	-84.02	41.20	0.05	1.42%	3.70	-25.39
	σ3	3.38	-16.36	173.54	3.28	-7.96	174.90	0.10	2.99%	-8.40	-1.36
	σ1	14.50	-13.69	85.16	14.23	-14.88	84.10	0.27	1.89%	1.19	1.06
M7	σ2	5.64	-68.26	193.93	5.51	-70.13	197.20	0.13	2.38%	1.87	-3.27
	σ3	3.78	-32.97	350.63	3.65	-29.75	349.80	0.13	3.54%	-3.22	0.83
	σ1	4.75	-2.45	185.23	4.56	-7.24	190.60	0.19	3.92%	4.79	-5.37
M8	σ2	3.68	-44.44	276.25	3.71	-24.49	282.20	-0.03	0.82%	-19.95	-5.95
	σ3	3.21	-60.50	92.94	3.30	-75.26	86.00	-0.09	2.80%	14.77	6.94
	σ1	17.10	-24.99	74.49	16.69	-26.28	78.40	0.41	2.37%	1.28	-3.91
M10	σ2	5.48	-14.89	167.89	5.61	-20.06	343.30	-0.13	2.37%	5.17	-175.41
	σ3	4.98	-73.19	285.82	4.74	-70.54	219.30	0.25	4.92%	-2.65	66.52
	σ1	9.69	-24.72	74.56	9.38	-20.44	72.80	0.31	3.18%	-4.28	1.76
M11	σ2	2.38	-14.28	167.76	2.39	-72.10	201.80	-0.01	0.29%	57.82	-34.04
	σ3	1.50	-73.55	284.98	1.44	-23.04	338.30	0.06	4.20%	-50.51	-53.32
	σ1	17.60	-12.04	67.62	16.67	-7.67	68.80	0.93	5.28%	-4.36	-1.18
M14	σ2	4.94	-65.68	323.28	5.09	-70.54	327.60	-0.15	3.12%	4.86	-4.32
	σ3	2.35	-36.91	162.14	2.18	-31.33	161.10	0.18	7.45%	-5.58	1.04

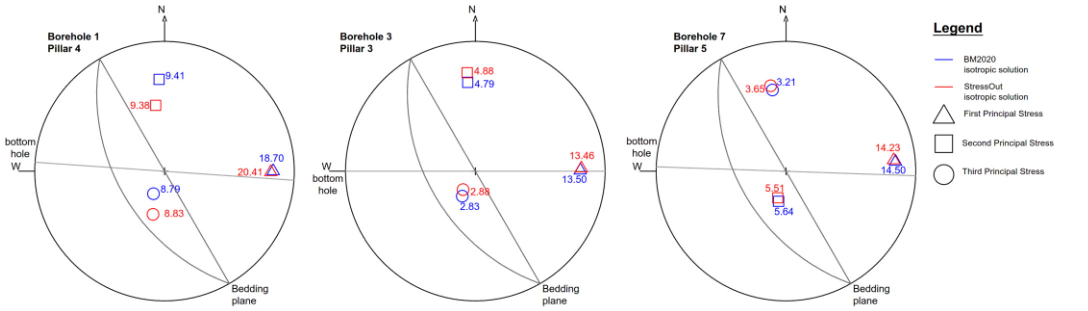

Figure 7. Stereographic projections of the maximum principal stresses acting in three selected abandoned pillars of the underground quarry under study. The numerical evaluations were conducted in the hypothesis of a linear, elastic and isotropic behavior of the rock, thanks to the StressOut and BM2000 softwares. Red marks refer to the results of the numerical analysis performed thanks to StressOut code, blue marks to those obtained with the BM2000 code. The symbols Δ, □, ○, respectively identify the maximum principal stresses σ_1, σ_2, σ_3, in MPa. The picture also indicates both the direction of the survey hole and that of the bedding plane.

For the analyzes carried out according to the second hypothesis (rock with linear, elastic, transversely isotropic behavior), the same elastic constants were used for each test carried out, as proposed in the literature [18] and given in table 4.

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Table 4. Elastic constants of the rock under study in the hypothesis of linear, elastic, transversely isotropic behavior. E_1, μ_1= Young's modulus and Poisson's ratio evaluated perpendicularly to the bedding plane; E2=E3, μ_2=μ_3 Young's modulus and Poisson's ratio evaluated parallely to the bedding plane.

Borehole	E_1 [MPa]	μ_1 [-]	E_2, E_3 [MPa]	μ_2=μ_3 [-]	$G_{12,13}$ [MPa]	G [MPa]
M1÷M14	39000	0.17	47000	0.25	18500	15600

Table 5 shows the results of the analyzes carried out assuming a linear, elastic, transversely isotropic behavior typical of metamorphic rocks such as marble, in terms of maximum principal stresses and of their directions. figures 8 shows three of the results obtained under the second hypothesis, using stereographic projections.

Table 5. Maximum principal stresses and their directions obtained from the processing of "stress relief" data by overcoring of 8 HI cells made integral with the pilot holes drilled in the centerline of as many abandoned pillars in an underground quarry. The interpretation of the data was carried out according to a hypothesis of a linear, elastic, transversely isotropic behavior of the rock, thanks to the BM2000 software.

		BM2000 Isotropic solution			BM2000 Transverse isotropic solution			Differences			
		[MPa]	Delta [°]	Beta [°]	[MPa]	Delta [°]	Beta [°]	Δσ [MPa]	% Δσ	Δ Delta [°]	Δ Beta [°]
	σ1	18.70	-14.64	89.99	20.60	-13.09	91.23	-1.90	10.16%	-1.55	-1.24
M1	σ2	9.41	-26.15	356.55	10.70	-11.49	182.42	-1.29	13.71%	-14.66	174.13
	σ3	8.79	-72.56	206.40	9.87	-80.64	312.82	-1.08	12.29%	8.07	-106.42
	σ1	13.50	-17.15	89.71	13.20	-17.24	90.65	0.30	2.22%	0.09	-0.94
M3	σ2	4.78	-28.21	354.96	4.42	-21.46	357.41	0.36	7.53%	-6.75	-2.45
	σ3	2.82	-70.47	207.49	2.39	-74.34	217.36	0.43	15.25%	3.87	-9.87
	σ1	7.94	-6.86	264.51	12.40	-9.67	264.57	-4.46	56.17%	2.81	-0.06
M6	σ2	3.79	-80.33	15.81	5.72	-78.77	147.82	-1.93	50.92%	-1.56	-132.01
	σ3	3.38	-16.36	173.54	5.33	-17.96	355.90	-1.95	57.69%	1.60	-182.36
	σ1	14.50	-13.69	85.16	16.50	-11.47	85.89	-2.00	13.79%	-2.21	-0.73
M7	σ2	5.64	-68.26	193.93	7.02	-64.74	188.80	-1.38	24.47%	-3.52	5.13
	σ3	3.78	-32.97	350.63	4.59	-38.26	351.28	-0.81	21.43%	5.29	-0.65
	σ1	4.75	-2.45	185.23	5.44	-11.71	189.14	-0.69	14.53%	9.26	-3.91
M8	σ2	3.68	-44.44	276.25	4.46	-48.69	285.91	-0.78	21.20%	4.25	-9.66
	σ3	3.21	-60.50	92.94	3.55	-55.67	90.00	-0.34	10.59%	-4.83	2.94
	σ1	17.10	-24.99	74.49	14.30	-26.74	74.46	2.80	16.37%	1.74	0.03
M10	σ2	5.48	-14.89	167.89	4.52	-19.72	169.57	0.96	17.52%	4.83	-1.68
	σ3	4.98	-73.19	285.82	3.23	-70.40	292.61	1.75	35.14%	-2.79	-6.79
	σ1	9.69	-24.72	74.56	13.50	-20.70	74.73	-3.81	39.32%	-4.02	-0.17
M11	σ2	2.38	-14.28	167.76	3.22	-68.09	195.43	-0.84	35.29%	53.81	-27.67
	σ3	1.50	-73.55	284.98	1.87	-29.89	338.40	-0.37	24.67%	-43.66	-53.42
	σ1	17.60	-12.04	67.62	12.30	-12.33	66.34	5.30	30.11%	0.29	1.28
M14	σ2	4.94	-65.68	323.28	2.49	-67.74	320.02	2.45	49.60%	2.06	3.26
	σ3	2.35	-36.91	162.14	1.07	-34.10	160.48	1.28	54.47%	-2.81	1.66

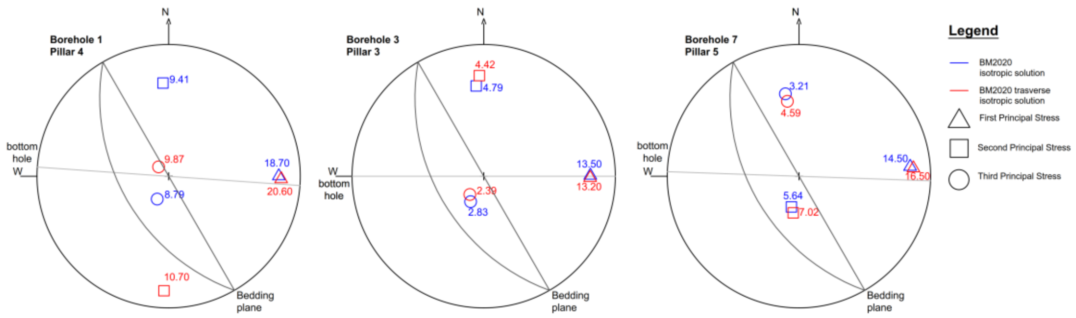

Figure 8. Stereographic projections of the maximum principal stresses acting in three selected abandoned pillars of the underground quarry under study. The numerical evaluations were conducted in the hypothesis of a linear, elastic, isotropic and transversely isotropic behavior of the rock, thanks to the BM2000 software. Blue marks refer to the results of the numerical analysis performed into the hypothesis of isotropic material, red marks to those obtained with into the hypothesis of a transversely isotropic material. The symbols Δ, □, ○, respectively identify the maximum principal stresses σ_1, σ_2, σ_3, in MPa. The picture also indicates both the direction of the survey hole and that of the bedding plane.

6. Conclusions

The campaign of stress state measurements conducted with the HI cell over-coring method equipped with the miniaturized data-logger called *micro12* highlighted that the device is easy to use and "insensitive" to the disturbances affecting analogous experimental tests conducted with Classic HI cells (equipped with an electric cable to provide the connection between the sensor and the measurement control unit). Another important advantage of the *micro12* is the simplicity of retrieving and reusing it. In fact, to perform a new stress state measurement, the HI cell can be easily separated from the device, the batteries recharged and the device can be connected to another HI cell. The check of the measuring instrument takes place automatically whenever desired by connecting the instrument to a special electronic board and running a specific calibration program. Among the other characteristics of the *micro12*, it is worth to highlight that:

- its static memory allows the storage of the experimental tests for a long time, even in lack of energy in the batteries. Just recharge the batteries and the *micro12* fully resumes its operation providing, where required, to transfer the data stored in the memory to a PC;
- having continuously available the whole strain - time diagram during the data interpretation allows detailed evaluations on the different phases of the measurement. In fact, it is easy to accurately evaluate the possible thermal drift of the strain gauges in the start-up phase of the over-coring and the intensity of the relief of each single strain gauge during the overcoring. It be also possible to discriminating the passage time of the diamond drilling crown in correspondence of the single strain gauge along the HI cell, as well as any progress of the measured strain after having completed the overcoring;
- while planning the on-site measurements, the use of Hi cells connected to the micro12 allows the reduction of the times needed for each individual experimental test. In fact, the removal of the connection cable between the HI cell and the measurement control unit greatly simplifies the construction site operations [9];
- the only limit to the depth in the hole where a stress state measurement has to be made is represented by the polymerization trigger time of the two-component resins used for bonding the HI cell to the rock.

A HI cell specially designed to be connected to the *micro12* data-logger is currently being tested at the IGG - CNR Rock Mechanics Laboratory.

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