The Furnas Type II Stress Measurement Cell

Ludger Suarez-Burgoa
ISRM Young Members' Presidential Group for the South American Region

Since around 1930, methods and tools where developed in the world in order to attain rock mass in-situ stress field measurements (e.g. surface overcoring, flat jack, borehole overcoring, and hydraulic fracturing). Nowadays, there exist diverse methods and equipments that attempt to assess in the best way the natural stress tensor in rock mass. Variations exist from one country to other, each of one tried to develop their own technology, own known-how and own state-of-the art.

This was not an exception in South America. Since the middle of the nineties of the past century, the research group of Doctor João Luiz Armelin, they dependent by the Brazilian State Company FURNAS (today named ELECTROBRAS - FURNAS), and in academic collaboration with some universities of the region, developed the Furnas Type II Stress Measurement Cell, a cell that adopted the overcoring concept to measure in a point the *in-situ* stress tensor in the rock mass (Figure 1).

Figure 1, Doctor Armelin with the Furnas Type II Stress Measurement Cell

The beginning

The idea of developing the cell begun in the seventies of last century, when Doctor Armelin, still a young graduate geological engineer, worked in the Energetic Company of the São Paulo State (CESP: *Companhia Energética de São Paulo*) for the *Ilha Solteria* Project, in the state of São Paulo (Brazil). There, he have close contact with Professor Manuel Rocha of the National Laboratory of Civil Engineering of Portugal (LNEC: *Laboratório Nacional de Engenharía Civil*) and later he had the opportunity to be close related with the *in-situ* stress tensor assessment campaign of Professor Bezalel Haimson and their collaborators, who were performing hydraulic-fracturing measurement for the *Serra da Mesa* Project (Figure 2).

To this respect, Doctor Armelin commented:

> The contact with Professor Manoel Rocha arose still in the CESP. He was a consultant for a variety of works of the CESP in the state of São Paulo. Because we worked in the CESP laboratory, in *Ilha Solteria*, his presence was frequently in the laboratory and he encouraged several researches about flat jack for the determination of in-situ stresses in sedimentary rock masses… In one opportunity we could talk with Professor Rocha about the triaxial cell and the overcoring techniques.

Then, Doctor Armelin was part of the professional group designated to arrange the new Rock Mechanics Laboratory of FURNAS, located until now in Goiânia (Brazil). Therefore, he and their comrades decided to develop for this institution an own overcoring cell.

The research

Even though the enthusiasm, desire and ideas about the own *Brazilian cell* was in the minds of these young engineers of the Rock Mechanics Laboratory of FURNAS, the research begun only 20 years after.

Figure 2, Professor Bezalel Haimson rounded by a group of Brazilian professional in the hydraulic-fracturing measurements campaign for the *Serra da Mesa* Project in 1975 (Doctor Armelin is at the right hand of Professor Haimson)

It was around the middle of the nineties of last century, when the research project for developing the cell really starts under the support of FURNAS; and for around 15 years all research milestones were accomplished one by one in order to have nowadays (for the beginning of the second decade of this century) the Furnas Type II Stress Measurement Cell.

The research first defined the geometrical dimensions of the future overcoring cell. It looked for the best diameter to length ratio of the core of the cell (where the strain gages are attached), and the proper quantity and position of the active strain gages around the cell core. Other goal in defining the proper geometrical values for the cell was to obtain a cell to be easy operated in standard boreholes with standard drill-hole tools. These permitted today use the Furnas Type II Stress Measurement Cell with the EW and HW drill series.

After obtaining the optimum cell size and desired strain gages arrangement, the next challenge was to reduce the rigidity of the cell core to a minimum possible value. Therefore, some materials were tested in order to finally choose a low viscosity epoxy resign as the cell material.

Then, physical and numerical models, and comparative *in-situ* tests with known international cells (i.e. the CTT and CSIRO cells) were performed, all of these in order to verify the efficiency of the developed cell. The physical tests consisted to stress cubes, orthotropic in stress-strain behavior, to polyaxial normal stresses; and then simulate the complete process of *in-situ* stress measurement with the new cell. This experience was repeated by using 3D numerical finite element method models (Figure 3).

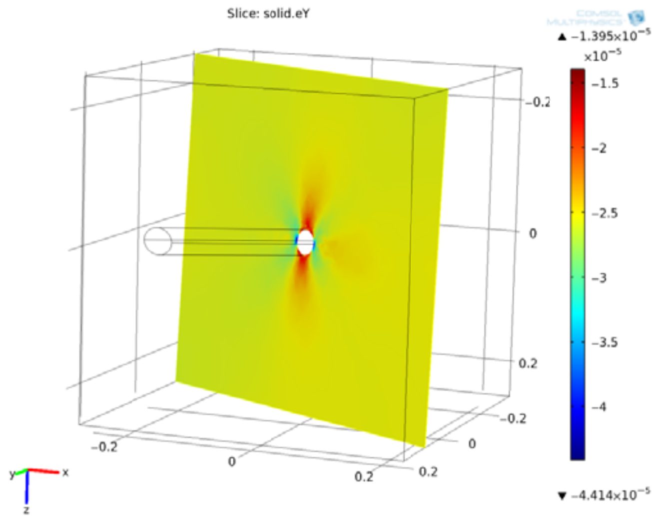

Figure 3, Three dimensional numerical model simulating the stress measurement process with the Furnas Type II Stress Measurement Cell

After that, the attention was concentrated to have an efficient and robust data acquisition system module to be coupled to the cell (Figure 4), and finally the research finished with the development of a properly software (named CaTMIso) for the data interpretation. This software helps reduce the interpretation time and the possibility to have calculations errors.

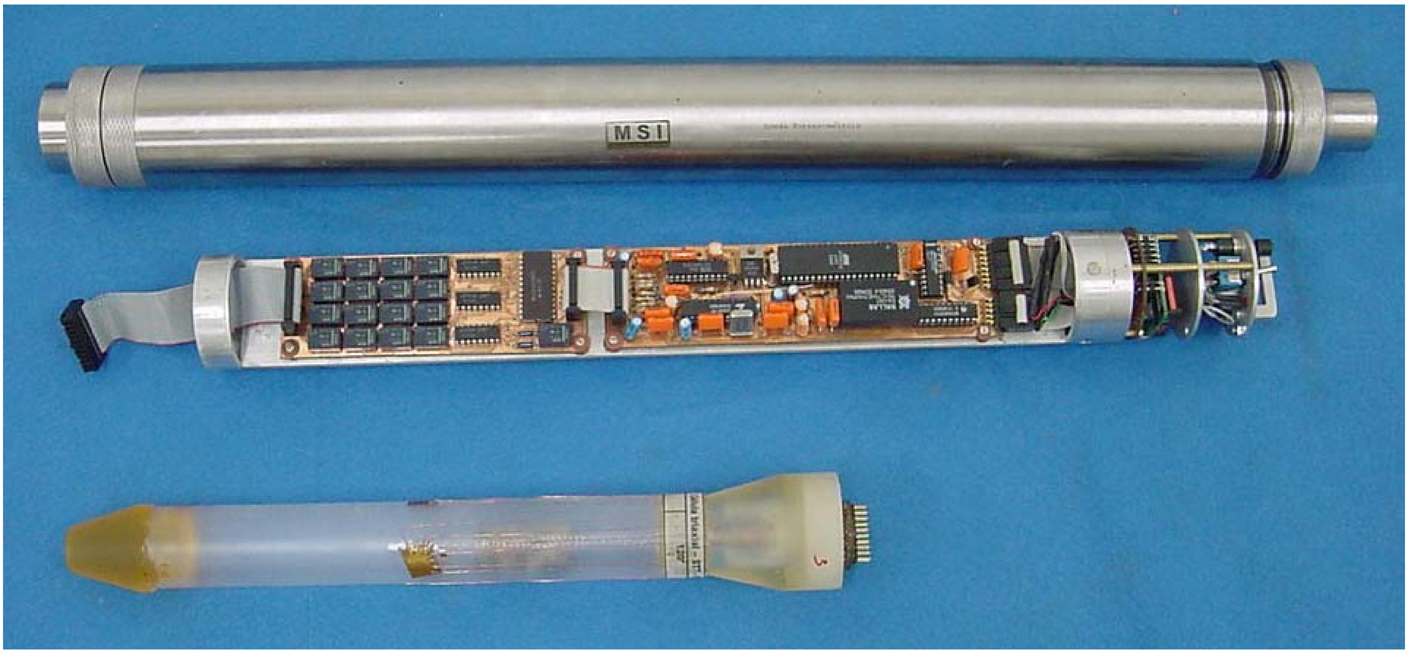

Figure 4, The core cell, the data acquisition system module and the protection tube of the Furnas Type II Stress Measurement Cell

Nowadays the Furnas Type II Stress Measurement Cell is ready to act as a reliable measurement system for punctual stress tensor measurement in the rock mass by the overcoring method. Real tests (i.e. those tests not performed as part of the research program) were just performed in Brazilian projects, which shown to the industry good results.

To this respect, Doctor Armelin commented:

> ...we performed measurements besides those initials at the Serra da Mesa project, which is the major site of stress assessment present in Brazil… we made also measurements in the Caraíba mine; and we compare the LNEC cell with our cell. Under the interpreters' point of view, which were not us who made the interpretations (referring to FURNAS personnel) because a series of reasons, they adopt a favorable position to the Furnas model cell.

Parallel research

The stress measurements with overcoring methods are still bringing some external influences that can modify the true values; these are mainly the temperature and the rock material mineral or micro fracturing size distribution present in rock mass.

During the development of the Furnas Type II Stress Measurement Cell, parallel research were done with the objective to minimize the temperature effect in the strain measurements of the extensometers and deduce the size effect of rock mass on stress measurements.

Future research

Future research is programmed in order to achieve full temperature compensation during the overcoring process, trough an adequate instrumentation.

To this respect, Doctor Armelin commented:

> ... the technical difficulty that still remains is in respect to the temperature compensation of the extensometers; this is a suggestion for us in order to maintain the research in this direction.

Technical data

The reference cell, from which this new cell was developed, was basically a foreign model, which for its initial version it proposed seven active strain gages. Because of the name "II" in the actual Furnas cell, one can perceive that an antecessor to the Type II existed, the Furnas Type I Stress Measurement Cell. This cell was primary the Brazilian version of the foreign model, but the Type II added the following improvements:

- It has a low rigidity core cell
- It has more strain gages for measurements in order to have more redundancy in more directions
- Their readings are more sensible
- It is applicable for conventional drilling equipments and tools

The core cell is made of a polymer (i.e. low viscosity epoxi resin), cylindrical in shape with a diameter to height ratio of 1/6 and 1 mm of thickness. It has 12 active strain gages (four strain gages in three groups), these coupled to the external face of the low rigid cylinder and protected externally with a thin layer of epoxy. Each strain gage group is located 120° to each other when looking the transversal section of the core cell, and they are rotated some grades around their own radial axis. Also, each strain gage in a group, is rotated 45° to each other (Figure 5).

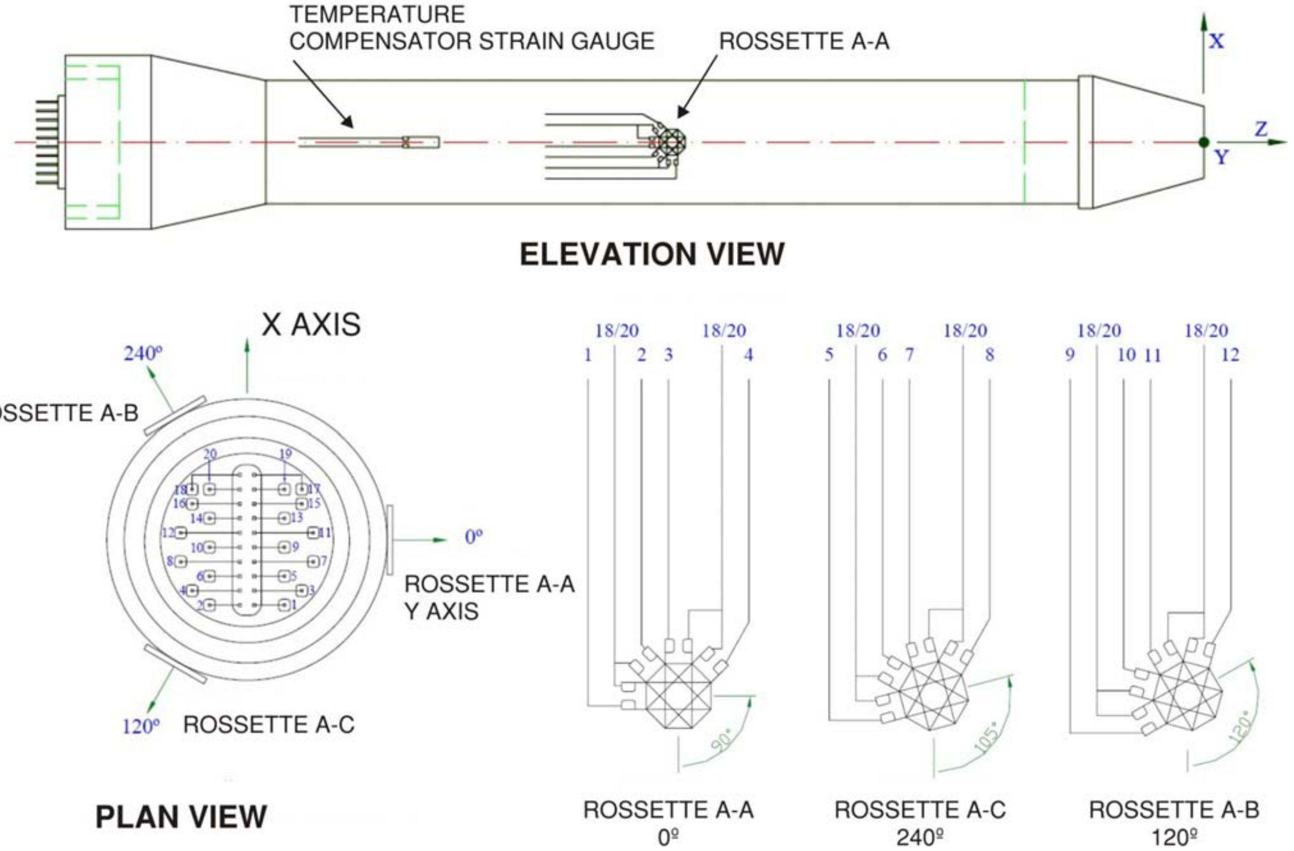

Figura 5, The strain gages arrangement in the core cell of the Furnas Type II Stress Measurement Cell

In the interior of the cylinder, the core cell has one dummy strain gage for compensations, this coupled to a rock material block (i.e. the same rock material in where the measurements will be performed), and finally the core cell incorporates in addition one temperature transducer.

The data acquisition system module incorporates an electronic compass, multiplexers, a memory card, a communication port, some led, a stopwatch trigger, a main circuit that performs the control tasks of: computing, storing and transmitting, and an energy supplier.

A biaxial cell to assess the elastic variables of the rock on cylindrical HX samples was also designed to make possible calculations.

Final notes

The Furnas Type II Stress Measurement Cell was only possible with the help of al lot of persons that actuate efficiently at the different stages of the research. To tell this history in a compressed way will always deal in the involuntary error to omit one or more of those persons. But, from this report authors' opinion, was Doctor Armelin the principal person of the good results of this research.

Interesting documents about the Furnas Type II Stress Measurement Cell and its development may be found in the following references:

Armelin, J.L., 2010. In-situ stress measurement in rock masses and concrete structures (In Portuguese). PhD Thesis, Document G.TD-066/2010, Department of Civil and Environmental Engineering, University of Brasilia, Brasília, DF, p: 305.

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