About the Determination of the In-Situ State of Stress

by

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Abstract: The paper presents the 2 main methods for the determination of the in-situ state of stress in rock masses, developed by the LNEC, and refers to a practical case in which they were used, at an underground pow-erhouse in northern Portugal.

1 Introduction

In many rock mechanics projects, one of the main issues is the knowledge of the state of stress occurring at the site.

For this reason, the Laboratório Nacional de Engenharia Civil (LNEC), the Portuguese state civil engineering laboratory, developed several methods for the determination of the in-situ stress in rock masses, which it has been using at many different sites, both in Portugal and abroad.

This paper presents the 2 more important of these methods, and refers to a practical case of determination of the in-situ state of stress, at an underground powerhouse in northern PORTUGAL.

2 The STT Method

2.1 General

The principle of this method is to measure the deformations incurred by a borehole core, due to its overcoring.

The 4 main steps of a test are:

a) drilling of a large diameter borehole, up to the vicinity of the point of the rock mass where the state of stress is to be determined;

b) drilling of a small diameter borehole, up to a depth which allows the positioning of the measuring device in it;

c) placing of the measuring device in the small diameter borehole;

d) overcoring of the small diameter borehole with the measuring device in it.

The specificity of the STT method lies in the measuring device it uses.

2.2 The measuring device

The measuring device used by the LNEC, has been improved several times.

Its 1st version, which was named STG (stress tensor gauge), was introduced to the rock mechanics community at the 1st International Congress on Rock Mechanics, held in 1966, in Lisbon PORTUGAL (Rocha, 1967).

It was a full epoxy resin cylinder, with 9 embedded electrical resistance strain gauges, and designed to fit into an EX (37 mm) diameter borehole (Fig. 1).

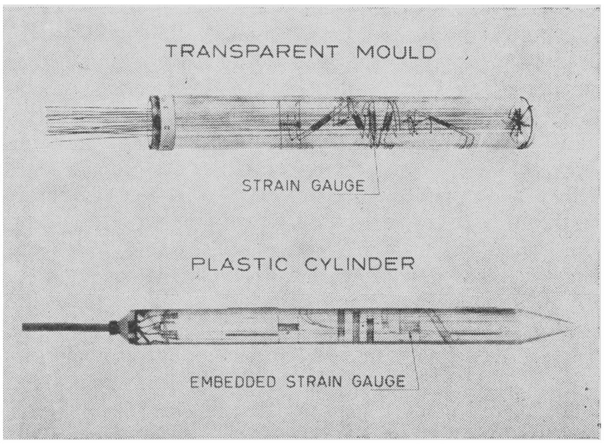

Fig. 1 – Stress tensor gauge (STG)

A full description of the measuring device, as well as of the complete testing method, was given at the International Symposium on the Determination of Stresses in Rock Masses, held in 1969, again in Lisbon (Rocha & Silvério, 1971).

The 2nd version was developed in 1974, and formally presented a year later (Rocha et al., 1975).

It was now a hollow epoxy resin cylinder – reason why, after some time, it was renamed STT (stress tensor tube) –, having 3 rosettes with 3 electrical resistance strain gauges each (Fig. 2), and, again, a length of about 40 cm.

Among other sites, this version of the measuring device was applied at the Mingtan Pumped Storage Project, in Taiwan CHINA (LNEC, 1978).

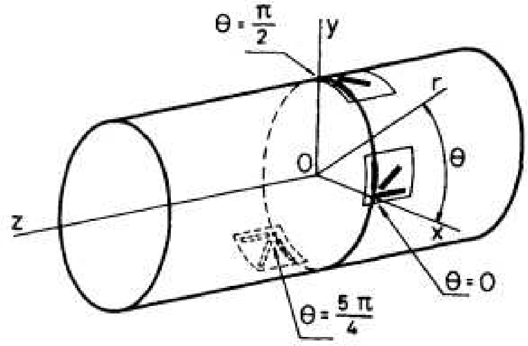

Fig. 2 – Position of the electrical resistance strain gauge rosettes in the 1974 version of the stress tensor tube (STT)

The 3rd version was introduced at the 14th International Congress on Large Dams, held in 1982, in Rio de Janeiro BRAZIL (Graça, 1982), and presented to the rock mechanics community at the International Symposium on Rock Stress and Rock Stress Measurements, held in 1986, in Stockholm SWEDEN.

It was also a hollow epoxy resin cylinder, but, now, with a length of only 25 cm, and with 10 electrical resistance strain gauges, having the attitudes corresponding to those of the 10 normals to the faces of a regular icosahedron (Fig. 3).

Fig. 3 – 1982 version of the stress tensor tube (STT)

Among other sites, this version of the measuring device was applied at the Arun 3 Hydroelectric Project, in NEPAL (LNEC, 1990).

The 4th and, for the moment, last version was developed in 2007, and has been applied, for the first time, at the new powerhouse of the Bemposta dam, in northeastern PORTUGAL (LNEC, 2008).

It is very similar to the previous version, except that, now, the cable for the reading of the electrical resistance strain gauges has been replaced by an automatic data acquisition system, and the temperature compensator by a thermoelectric temperature reading device, which is also connected to that data acquisition system (Fig. 4).

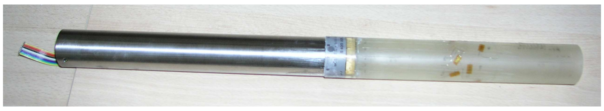

Fig. 4 – Current version of the stress tensor tube (STT)

2.3 The main difficulties of the method

With the 3 versions of the measuring device which possessed a cable for the readings, the first difficulty in the field was the execution of the watertight connexion between the measuring device and the appropriate length of cable, which also implied a lot of weldings, but this difficulty has now ceased to exist.

The cumbersome task of passing the cable through all the positioning rods has also vanished, and, so, the choice of the correct proportions of the different components of the glue is now the first task to be dealt with.

It implies a good knowledge of the hardening properties of the glue, as well as a correct estimate of the temperatures reigning both inside and outside the borehole, and of the time necessary to position the measuring device.

This time depends on the number of rods that have to be connected, which, in turn, depends on the depth where the test is going to be performed.

The introduction of the measuring device into the small diameter borehole is a very delicate operation, because only there the glue shall be extruded, the device rotated so that it hardens with the chosen orientation, and the rods disconnected from the measuring device.

The readings of the different electrical resistance strain gauges during the overcoring process are the most important result of the test, but they are now done by the automatic data acquisition system.

The careful extraction of the borehole core with the measuring device is necessary because the core shall then be submitted to a test in a biaxial testing chamber (Fig. 5), in order to obtain the elastic constants of the respective rock.

Fig. 5 – STT biaxial testing chamber

Finally, it should be stressed that the STT measures the state of stress in a very small zone of the rock mass, which may not be representative of the rock mass as a whole, for instance, due to the presence, in its vicinity, of discontinuities, of small cavities, of very soft or very stiff minerals, etc.

Therefore, it is advisable to perform always more than one test (preferably, 3 to 5) in each homogeneous zone of the rock mass for which one wishes to determine the state of stress.

3 The SFJ Method
3.1 General

The principle of this method is to determine the pressure necessary to annul the deformations produced by the cutting of a slot into the rock mass.

The 3 main steps of a test are:

a) cutting a slot in the exposed surface of a rock mass, in the vicinity of the point where the state of stress is to be determined;

b) inserting a flat jack into that slot;

c) determining the pressure in the jack for which the distances between points of the rock surface lying on opposite sides of the flat jack, are the same as they were before the slot cutting.

The specificity of the SFJ method lies in the slot cutting device it uses.

3.2 The slot cutting device

The slot cutting device developed by the LNEC, is a hand-driven, diamond-edged disk, with a diameter of 60 cm.

Its 1st version, which was also introduced to the rock mechanics community at the 1st International Congress on Rock Mechanics, (Rocha et al., 1966), was driven either by a compressed-air engine, or by an electric engine, by means of a sliding coupling and two Cardan joints (Fig. 6).

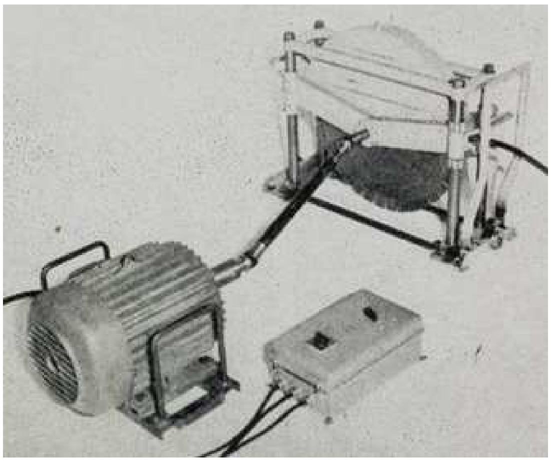

Fig. 6 – SFJ slot cutting device with the electric engine

Among other sites, this version of the slot cutting device, with the compressed-air engine, was applied at the Ernstbachtal Potable Water Dam, in GERMANY FR (LNEC, 1979).

The 2nd and, for the moment, last version was already developed some 15 years ago, and is driven directly by an oil engine, thus reducing substantially the area of the flat surface needed for the test (Fig. 7).

Fig. 7 – SFJ slot cutting device with the oil engine

Among other sites, this version of the slot cutting device was applied at the Middle Marsyangdi Hydroelectric Project, in NEPAL (LNEC, 1997).

3.3 The main difficulties of the method

As each slot only provides the normal stress occurring in the direction perpendicular to the slot, the knowledge of the full state of stress reigning in an exposed surface of the rock mass, requires the execution of, at least, 3, but, preferably, 4 non--parallel slots, at that location.

As all these slots must be at a certain distance from each other, in order to avoid that the presence of one slot changes the state of stress in the vicinity of another slot, with the 1st version of the slot cutting device, there was always a certain difficulty in finding an appropriate surface for the performance of the tests.

This difficulty has been minimized with the 2nd version of the slot cutting device.

If the aim is to determine the full state of stress in the chosen zone of the rock mass, one must find 3 non-parallel surfaces, and, in each of them, determine the state of stress reigning in that surface, i.e. one must cut, at least, 9, but, preferably, 12 slots.

Each SFJ test provides, as a by-product, the knowledge of the Young's modulus of the rock around the slot.

If a slot is cut in a weak zone of the rock mass, the SFJ test will also provide a low stress value.

A last major difficulty of the SFJ method is how to obtain the state of stress in the rock mass, as the method itself only provides the state of stress at the surface.

4 The Case of the Venda Nova II Powerhouse Cavern

The Venda Nova II underground power plant is located in northern PORTUGAL, in a very sound granite, with a Young's modulus of 40 GPa (LNEC, 2006), its main cavern having a length of 60.5 m, a width of 21.5 m, and a height of 48.05 m.

As the overburden is about 350 m, one of the main issues for the design was the correct estimate of the in-situ state of stress.

For this reason, a great number of different tests for the determination of the state of stress was performed, namely, 1 LFJ (large flat jack) test, 9 SFJ tests, and 6 STT tests (Fig. 8).

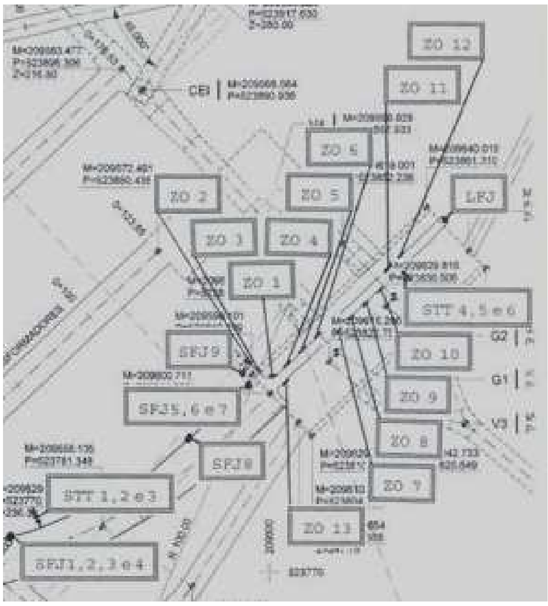

Fig. 8 – Locations of the different rock mechanics tests at the Venda Nova II powerhouse site (LFJ – large flat jack; SFJ – small flat jack; STT – stress tensor tube; ZO – jointing study)

The following state of stress was obtained:

a) a maximum principal stress which is approximately horizontal and normal to the main axis of the powerhouse cavern, its value being more than the double of the vertical stress;

b) an intermediate principal stress which is approximately vertical, and corresponds to the weight of the overburden;

c) a minimum principal stress which is approximately horizontal and parallel to the main axis of the powerhouse cavern, its value being somewhat less than the vertical stress.

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