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STRAIN MEASUREMENT ON A COMPACT NUCLEAR REACTOR STEAM GENERATOR

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ABSTRACT

This work presents the strain measurement procedures applied to a compact nuclear reactor steam generator, during a hydrostatic test, using strain gage technology. The test was divided in two steps: primary side test and secondary side test. In the primary side test twelve points for strain measurement using rectangular rosettes, three points (two external and one internal) for temperature measurement using special strain gages and one point for pressure measurement using a pressure transducer were monitored. In the secondary side test 18 points for strain measurement using rectangular rosettes, four points (two external and two internal) for temperature measurement using special strain gages and one point for pressure measurement using a pressure transducer were monitored. The measurement points on both internal and external pressurizer walls were established from pre-calculated stress distribution by means of numerical approach (finite elements modeling). Strain values using a quarter Wheatstone bridge circuit were obtained. Stress values, from experimental strain were determined, and to numerical calculation results were compared.

1. INTRODUCTION

The steam generator (GV1) is one of the equipments that belong to the CS-1 nuclear safety class of the primary circuit of the Nucleoelectric Generation Laboratory Reactor (LABGENE) that will be built in the facilities of the Navy Technological Center in São Paulo (CTMSP-ARAMAR), in Iperó, a city 80km from São Paulo city- Brazil.

The steam generator hydrostatic test aims to evaluate the stresses developed in the equipment during the pressurization and possible leaks through its weld beads, connections and gaskets. In order to evaluate the stresses [1, 2, 3] in the equipment during the hydrostatic test, rectangular strain gage rosettes were installed in both internal and external surfaces of the steam generator.

An independent inspector of the Brazilian Institute of the Nuclear Quality (IBQN) accompanied the whole test.

2. METHODOLOGY

2.1 Strain Gage Protection

To conduct strain gage measurement under pressurized water it was necessary to use an special protection on the internal strain gages. A protection was also used on the external strain gages by virtue of the risk to wet during the test. For protecting the internal strain gages, the protection AK22 was selected due to be efficient in cases of immersion in water under pressure up to 400 bar. For the protection of the external strain gages, the protection ABM75 was selected due to be efficient for situations where immersion can occur on the strain gages.

The internal points were protected with two varnish layers, MM™ (Vishay), model MCoat A; a thick layer of mass, HBM™, model AK-22; an aluminum foil leaf and adhesive tape 3M™, model silver tape.

The external points were protected with two varnish layers, MM™ (Vishay), model MCoat A; a mass layer with leaf of aluminum, HBM™, model ABM75 and adhesive tape 3M™, model silver tape.

2.2 Strain Gages Connections

Each gage (the rectangular rosette possesses 3 gages) was connected through a cable with 3 armored threads to the Wheatstone bridge as presented in Fig. 1. The Wheatstone bridge was set up, being strain gages rectangular rosette model CEA-06-250-UR-120 manufactured by Measurements Group bounded in bars of steel rigid not submitted to mechanical efforts. The Wheatstone bridge was installed close to the rosettes to minimize the size of the threads of the strain gage connection.

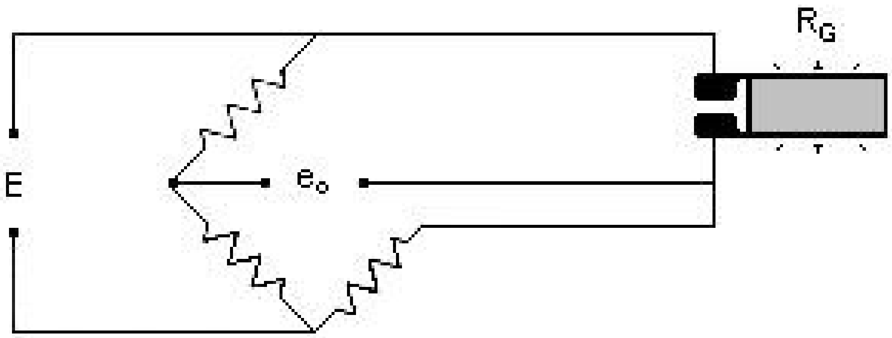

Figure 1. Connection of the strain gage to the Wheatstone bridge.

A cable with 4 armored threads was used to connect the bridge of Wheatstone to the data acquisition system and the feeding source. To the data acquisition system were connected the terminals suitable e_0 in Figure 1 and the terminals E were connected to the power supply.

The Wheatstone bridge was fed with 2 volts and this value was monitored by the data acquisition during the measurements.

The connection of the internal points was done through the use of feed through, CONAX™, model HD37-450(60Cu) PG4AL-70/24.

Acquisition and Data Treatment System**:**

The acquisition and data treatment system was composed by:
01 system with 48 channels, Agilent™, model 34970A, with 03 modules of switch, model 34902A.
01 system with 60 channels, Agilent™, model 34970A, with 03 modules of switch, model 34901A.
01 microcomputer type notebook, Texas Instruments™, Extensa model 610CD, Pentium 133 Mhz.

2.3 Internal pressure measurements of the steam generator

The internal pressure in primary and secondary sides of the steam generator (GV1) was accomplished by pressure transducer Gefran™, model TK-E-3-E-B35D-M-V, range of reading from 0 to 350 bar. Simultaneously two manometers with calibration and certification both valid and updated accomplished the internal pressure.

2.4 Pressurization System

Sulzer (steam generator manufacturer) supplied the equipments for pressure application and for the pressurization rate control. The Sulzer team led the hydrostatic test.

2.5 Strain Gages Calibration

Analyzing the stress of pressure vases, the bounded strain gages in the internal surface are exposed to the flowed or pressurized gas, which acts directly in the strain gage element. Under such conditions, the resistance of the strain gages suffers a small increase due to the pressure that acts perpendicular to its grade and it should be taken into account for the strain gage readings analysis. For the strain gages used in this test, the correction is given by:

$$\frac{\Delta R}{R} = 0{,}016 \times 10^{-6} / MPa \tag{1}$$

2.6 Compensation due to the strain gage factor K

The compensation values were K = 2.11 for the strain gages used for the Steel SAE 508 class 3 and of K = 2.18 for the strain gages used for the Stainless Steel AISI 347. This compensation is made by using in the Equation (2) the K values described above.

$$\varepsilon = \frac{4e_0}{kE} \tag{2}$$

2.7 Factor of correspondence of the strain values

The readings were corrected through the technique of external shunt, using standard resistors of precision, MM™ (Vishay) model S-59880-01, tolerance 0.01%, whose equivalent strain is of 1000 µm/m for a nominal resistance of 120 ohms and factor K=2 of the strain gages. For this correction, readings were made in the points with and without the standard resistor inserted in parallel with the strain gages. The result of these readings was compared with calculated values being considered the resistance values and the factor K of the used strain gages.

2.8 Uncertainty of the Measurements

The whole measurement system was previously checked. The global uncertainty of the measured values was evaluated in 4% of the read values.

2.9 Measurement procedure

The GV1 hydrostatic test was divided into two steps: hydrostatic test of the secondary side and hydrostatic test of the primary side. In the primary side 12 points with rectangular rosettes, 3 points with temperature gage (2 internals and 1 external) and 1 point with pressure transducer were monitored. For data acquisition a system 34970A with 2 modules 34901A (each module with 20 channels) was utilized. In the secondary side 18 points with rectangular rosettes, 4 points with temperature gage (2 internals and 2 externals) and 1 point with pressure transducer were monitored. For data acquisition a system 34970A with 3 modules 34901A (each module with 20 channels) was utilized.

For data acquisition, storage and graphical presentation software provided by the equipment manufacturer, was utilized. The channels scanner was made in steps of 15 seconds.

In both primary and secondary side data acquisition were performed in two ways, with no pressure applied, with and without water filling.

Fig. 2 presents the location of the 30 rosettes and the 7 temperature gages, installed in the GV1 according the document V760.038 [1]. The document V760.038 Rev. 3 shows the final positioning of the gages. The gages identification was made according the document V760.038.

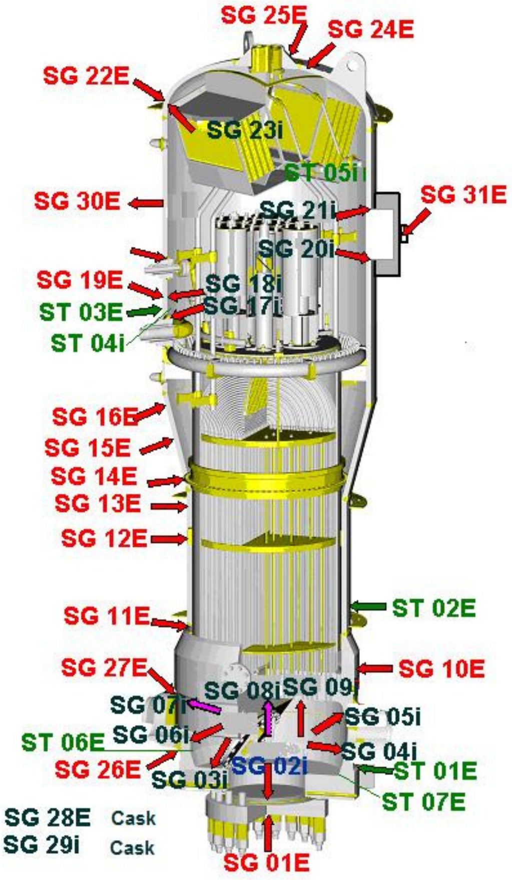

Figure 2. Schematic diagram of the measurement points

The rectangular rosettes were numbering from 1 to 3, counterclockwise, as showed in the Fig. 3.

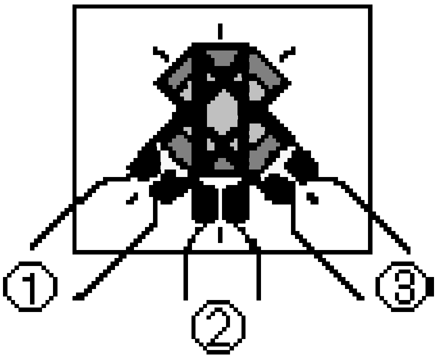

Figure 3. Strain gage orientation – Rectangular rosette

3. RESULTS AND DISCUSSIONS

In Fig. 4 the internal pressure values in the Steam Generator, for both primary and secondary sides are presented. The regions 1 and 3 refer to the design pressure and region 2 refers to the pressure test.

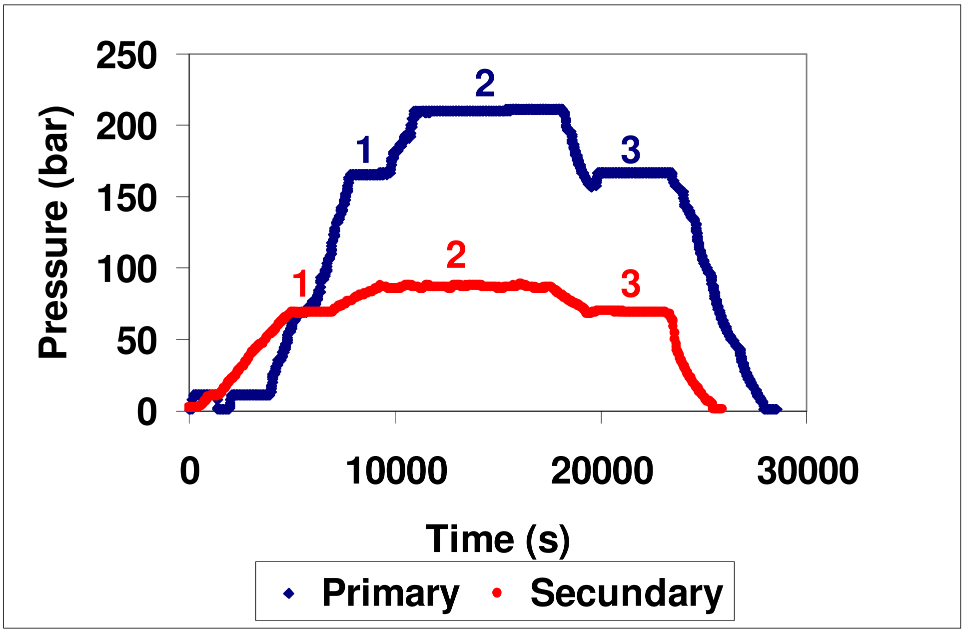

Figure 4. Internal pressure values in the primary side.

In Fig. 5 the internal and external temperature values into the Steam Generator wall, for both primary and secondary sides, are presented.

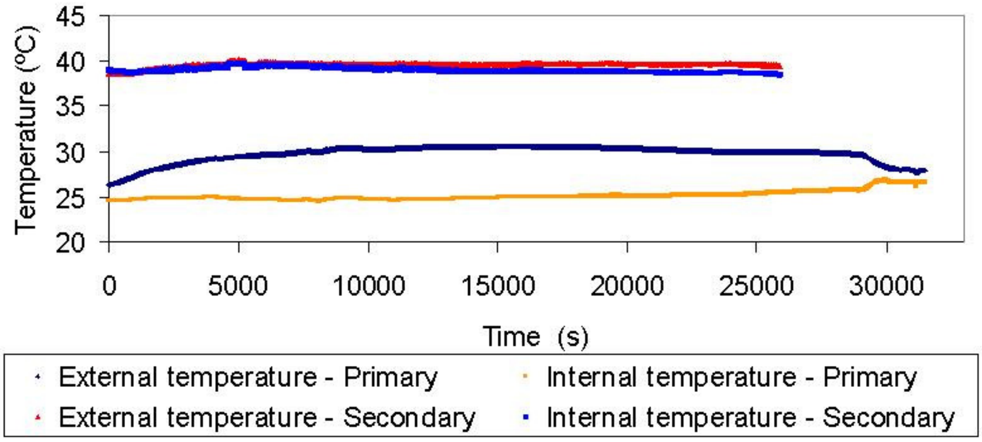

Figure 5. Internal and external temperature values in the Steam Generator.

In Fig. 6 and Fig. 7 the principal stresses, principal shear stresses and orientation of the maximum principal stress for point 1, in the primary side, are presented.

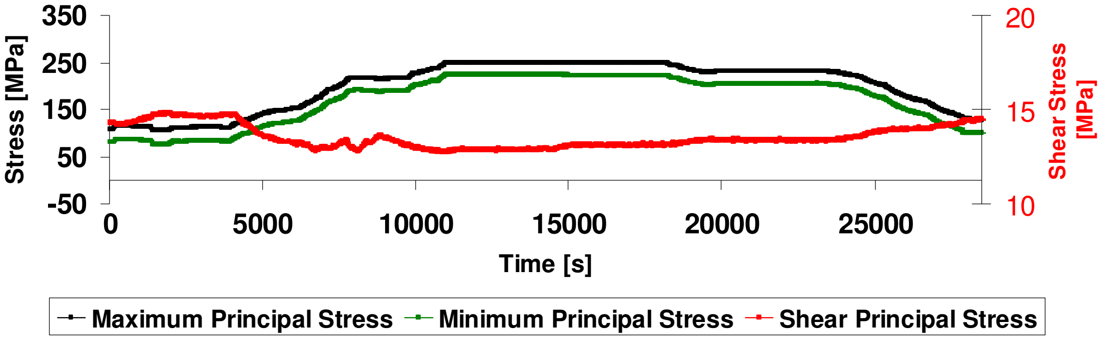

Figure 6. Principal stresses and principal shear stresses for point 1 in the primary side.

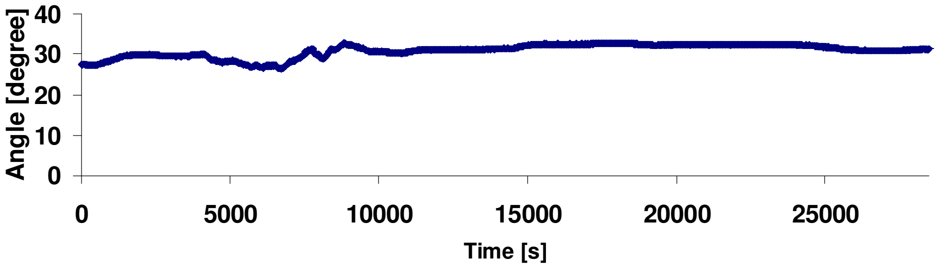

Figure 7. Orientation of the maximum principal stress for point 1 in the primary side.

In Fig. 8 and Fig. 9 the principal stress, principal shear stress, and orientation of the maximum principal stress for point 29, in the primary side are presented.

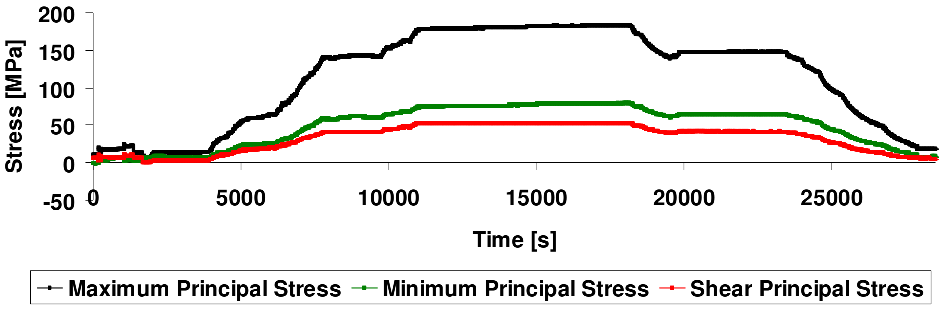

Figure 8. Principal stresses and principal shear stresses for point 29 in the primary side.

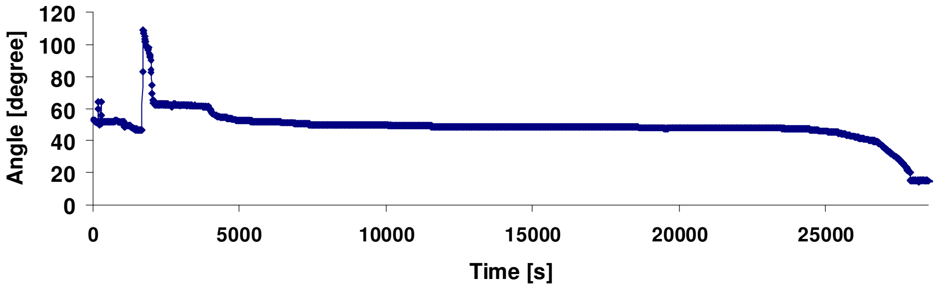

Figure 9. Orientation of the maximum principal stress for point 29 in the primary side.

In Fig. 10 and Fig. 11 the principal stress, principal shear stress and orientation of the maximum principal stress, for point 20 in secondary side, are presented.

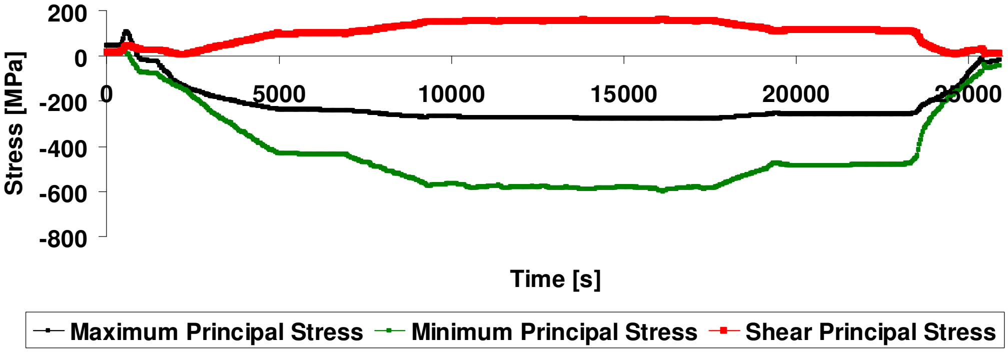

Figure 10. Principal stresses and principal shear stresses for point 20 in the secondary side.

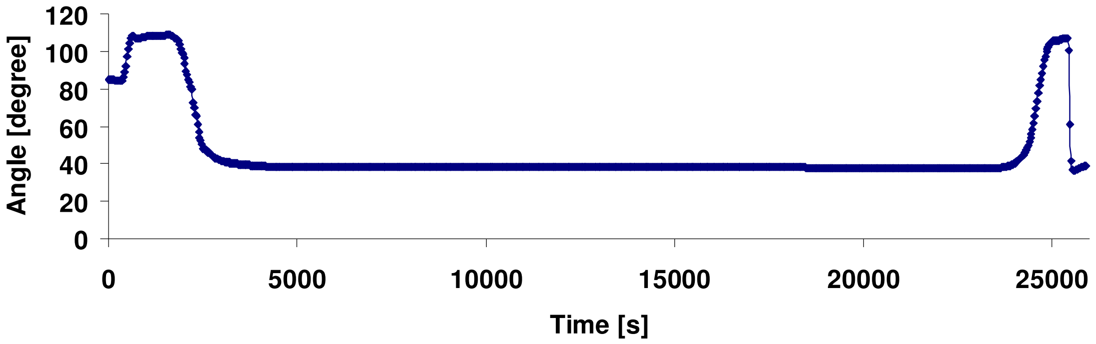

Figure 11. Orientation of the maximum principal stress for point 20 in the secondary side.

In Fig. 12 and Fig. 13 the principal stress, principal shear stress and orientation of the maximum principal stress, for point 30 in secondary side, are presented.

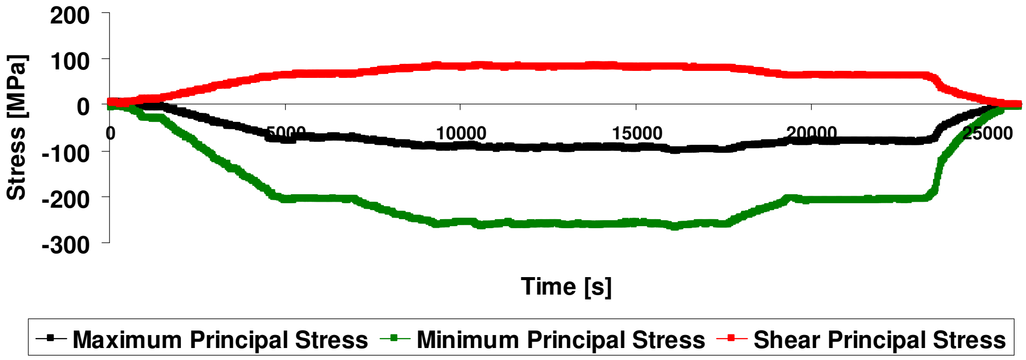

Figure 12. Principal stresses and principal shear stresses for point 30 in the secondary side.

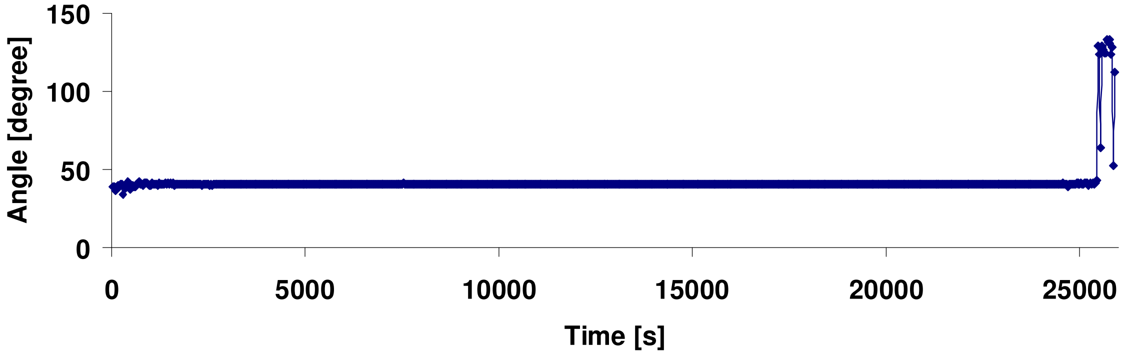

Figure 13. Orientation of the maximum principal stress for point 30 in the secondary side.

Fig. 14 shows a comparison between some experimental values and those calculated according to references 4 and 5, taking into account the corrosion or the clad. The experimental values used for comparison were taken as equal to the maximum value obtained to $|\sigma_1 - \sigma_2|$, $|\sigma_2 - \sigma_3|$, $|\sigma_3 - \sigma_1|$, $|\sigma_1|$ or $|\sigma_2|$ where $\sigma_1 = \sigma_{\max}$, $\sigma_2 = \sigma_{\min}$ and $\sigma_3 = -P$ (P is the design pressure). In Figure 14 the index "i" means a Steam Generator internal point and the index "E" means a Steam Generator external point.

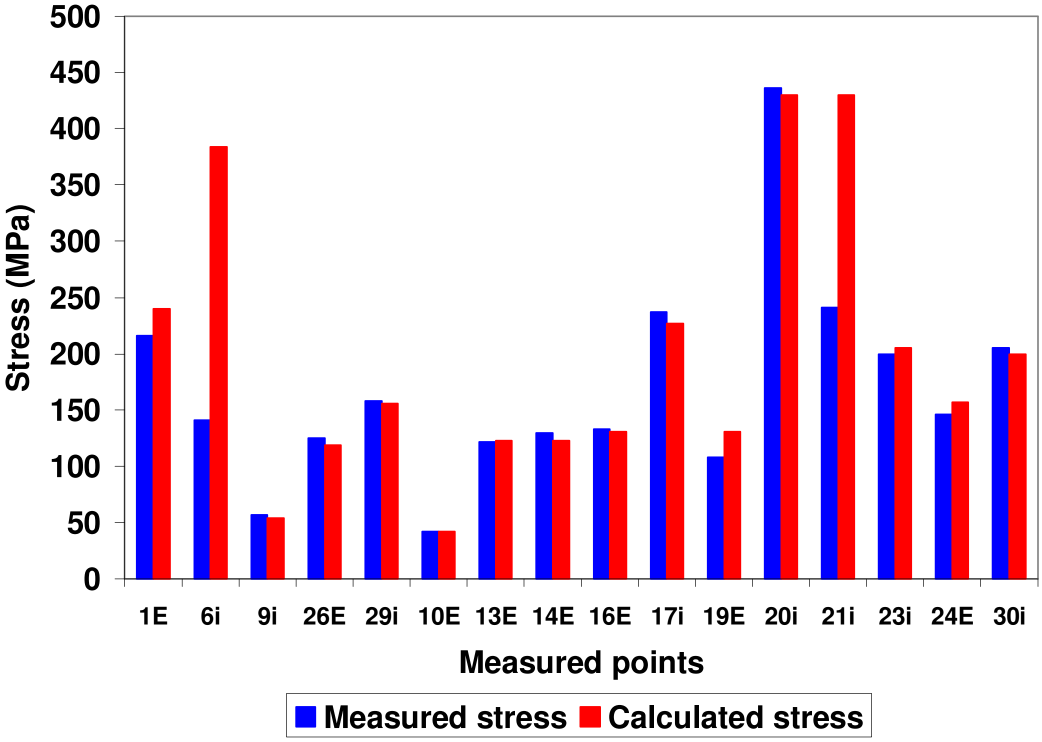

Figure 14. Comparison between experimental and theoretical stress.

4. CONCLUSIONS

The stability of the pressure and temperature values during the test (Figures 4 and 5) made it possible to measure deformation without fluctuation (Figures 6 to 13), which allows us to more realistically compare the experimental values with those obtained by finite elements.

All points presented experimental values very close to the calculated values [5, 6, 7] with the exception of the points 6 and 21, which showed the experimental values much lower than the calculated values. The location of the strain-gages may be the cause of these discrepancies, because in this region the stress variation is very sharp and a small displacement from the point of strain-gages bonding to the point used for calculating the finite element method can lead to large differences between measured and calculated strain values.

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