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STRUCTURAL DEFORMATION ANALYSIS OF A BAJA TYPE OFF-ROAD VEHICLE USING EXTENSOMETRY

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Abstract. *Among the fundamental quantities used to evaluate the structural performance of a vehicle, stand out the mechanical deformations which allow the determination of the acting stress in crucial points to the appropriate chassi sizing. Thus, the aim of this work is to monitor deformations in the structure of a type baja off-road vehicle, under normal conditions of use. To the deformations measurement, was used extensometry techniques, being used uniaxis strain gages and strain rosettes, compatible with the material used in the chassis construction. The monitoring points were selected in locals with highest stress based in results of CAE simulations, in which the vehicle was subjected to known loads. All the strain gages were coupled in acquisition modules from National Instruments® in which signals were acquired. There was an evolution in the development of the vehicle chassis by the extensometry utilization, getting a more rigid chassis and also getting relevant information to used mathematical models.*

Keywords: *instrumentation, stress analysis, machine design*

1. INTRODUCTION

"Baja" best known today as the chassis cage, built specifically for off-road routes, appeals for simplicity modification combined with multi-use characteristics of the car, is an inexpensive alternative to vehicles in this category. The chassis is built using steel pipe, has some restrictions in the geometry and on the arrangement of members changes that are important for ensure the safety of the pilot. Besides the pilot safety, the chassis has another important functions as to accommodate the sub-systems (suspension, engine and transmission, brakesand steering). Focusing on that, this cage need to have sufficient rigidity for do not suffer a deformation at a normal working situation.

The development of car design encompasses several phases. Including the construction and testing of prototypes. The reduction of development time can be achieved using instrumentation systems for feeding systems modeling and simulation, which results in decreasing the number of prototypes required until the final version. Deformation is an important analysis for evaluate the performance of a vehicle. The measurements of the strain that are applied on the chassis, allows to know the stresses and strains acting on it, that are important factors in the design of the geometry of the vehicle.

Measurement system with stress and strain with strain gages is commonly used in the automotive industry for the optimization of parts and components. The monitoring of the working conditions of a component allows you to optimize the project, which has repercussions on the productive process variables such as production time, material used, cost and weight.

The use of extensometry for measuring the deformation is a subject discussed in articles by various authors respected. Coclé and Chu (1997) worked in some vehicle prototypes in order to reduce the number of tests and projects, optimizing weight and measures beyond the project time. Palma et. al (2009) investigated the point of failure of a passenger vehicle trailer after a short working period. Oka et. al (1989) discussed the development of a system for fatigue analysis in steel bridges prioritizing inspections prone to fatigue.

Many engineering structures are designed to have relatively small deformations involving only the straight part of the stress-strain diagram (elastic part). For this initial part of the diagram, the tension σ is directly proportional to the specific deformation ε, and we can express:

$$\sigma = E.\varepsilon \qquad (1)$$

This relation (1) is known as Hooke's law, where E is called the modulus of elasticity of the material involved and the specific deformation ε is given by the ratio between the original length elongation (2).

$$\varepsilon = \frac{\Delta l}{l} \tag{2}$$

Real situations where mechanical stresses do not occur in one direction but in a plane or plane stress, (σ_x, and σ_y, τ_{xy}), as shown in Fig.1, the original axial σ and τ shear stresses may not be maximum stresses.

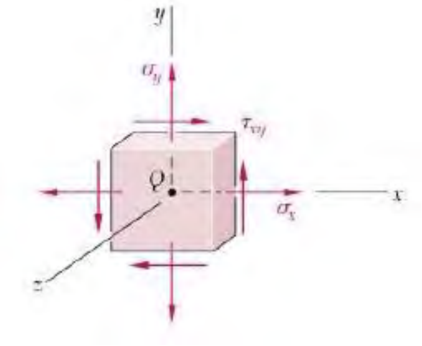

Figure 1 - State Plane Stress

The method proposed by Mohr, knows as Mohr's circle, is used for determine the maximum stresses.
Figure 2 shows the Mohr's circle for plane stress.

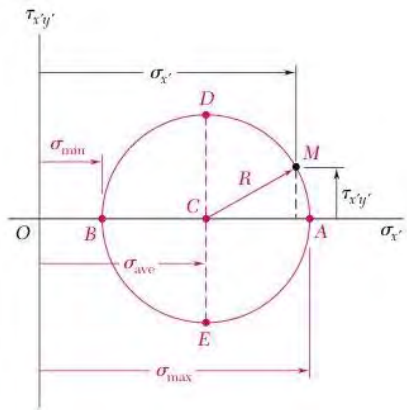

Figure 2 - Mohr's Circle for Plane Stress State

Through parametric equations of a circle (6), and from the analysis in static equilibrium Q, rotational θ around the z axis, it's possible determine the new stress in elementary cube $\sigma_{x'}$,$\sigma_{y'}$, $\tau_{x'y'}$ from of function σ_x, σ_y, τ_{xy} and θ being:

$$\sigma_{x'} = \frac{\sigma_x - \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2}.\cos 2\theta + \tau_{xy}.\mathrm{sen}2\theta \tag{3}$$

$$\tau_{x'y'} = -\frac{\sigma_x - \sigma_y}{2}.\mathrm{sen}2\theta + \tau_{xy}.\cos 2\theta \tag{4}$$

$$\sigma_{y'} = \frac{\sigma_x + \sigma_y}{2} - \frac{\sigma_x - \sigma_y}{2}.\cos 2\theta - \tau_{xy}.\mathrm{sen}2\theta \tag{5}$$

$$\left(\sigma_{x'} - \frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{x'y'}{}^2 = \left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2 \tag{6}$$

Reaching the maximum and minimum stresses,

$$\sigma_{máx,mín} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2} \tag{7}$$

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$$\tau_{máx} = \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_{xy}{}^2} \qquad (8)$$

Doing the same treatment for a plane strain under a rotation of the coordinate axes, we arrive at:

$$\varepsilon_{x\prime} = \frac{\varepsilon_x-\varepsilon_y}{2} + \frac{\varepsilon_x-\varepsilon_y}{2}.\cos2\Theta + \frac{xy}{2}.\mathrm{sen}2\Theta \qquad (9)$$

$$\varepsilon_{y\prime} = \frac{\varepsilon_x+\varepsilon_y}{2} - \frac{\varepsilon_x-\varepsilon_y}{2}.\cos2\Theta - \frac{xy}{2}.\mathrm{sen}2\Theta \qquad (10)$$

$$_{x'y'} = -(\varepsilon_x - \varepsilon_y).\mathrm{sen}2\Theta + {}_{xy}.\cos2\Theta \qquad (11)$$

And similarly for the Circle of Mohr, Fig. 3.

$$\varepsilon_{méd} = \frac{\varepsilon_x+\varepsilon_y}{2} \qquad (12)$$

$$R = \sqrt{\left(\frac{\varepsilon_x-\varepsilon_y}{2}\right)^2 + \left(\frac{xy}{2}\right)^2} \qquad (13)$$

$$\varepsilon_{máx,mín} = \varepsilon_{méd} \pm R \qquad (14)$$

$$\mathrm{tg}2\Theta_p = \frac{xy}{\varepsilon_x-\varepsilon_y} \qquad (15)$$

$$_{máx} = 2R \qquad (16)$$

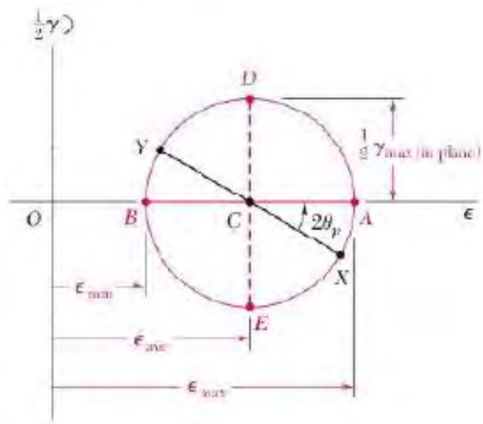

Figure 3 - Mohr's Circle for Plane Strain State

Extensometry is the technique used to measure strain, that apply the principle of the relationship between stress and strain in bodies subjected to mechanical stress, as established by Hooke's Law, in order to measure surface deformations of bodies.

The sensor that is used to measure deformations is strain gage. The principle of this equipment is based on the variation of the electric resistance, as consequence of the deformations applied on the surface to be measured, Fig. 4.

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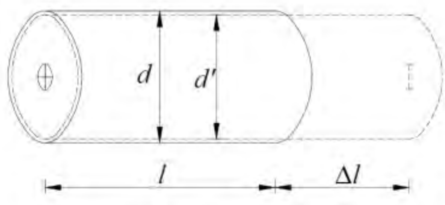

Figure 4: Principle of operation of the strain gage

The strain gage is divided in two parts: the base and the grid Fig. 5. The base allows fixation of the sensor surface and makes their isolation and generally consists of an epoxy or polyamide amine. The grid is the resistive element and it is formed by a metallic element.

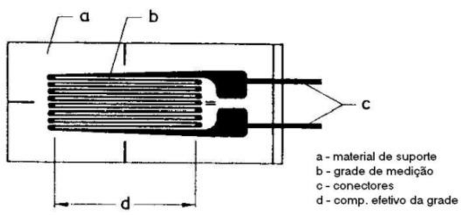

Figure 5 – Strain Gage

To measure the resistance variation of the strain gauge is used to Wheatstone bridge, which has a great accuracy with small variations. Applying a known voltage E, the voltage change e can be measure by the voltage change undergone the variable resistor (strain gage). Figure 6 illustrates the schematic model reaching the following relationship:

$$e \cong \frac{\pm E.K.\varepsilon}{4} \quad (17)$$

Where K is the sensitivity factor of strain gage, that depends on the material and this value is given by the manufacturer.

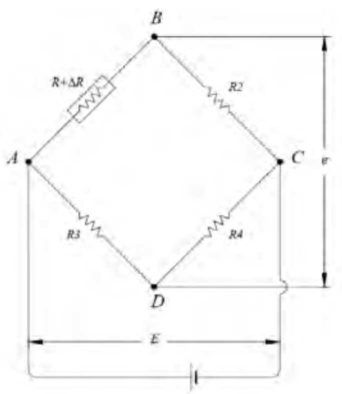

Figura 6 – Wheatstone bridge

2. OBJECTIVE

This study aims to monitor the deformations of a baja chassis type from the strain gage technique, applying the techniques required to accomplish the same, and find weak points and strengths to feed future models to be optimized.

3. METHODOLOGY

3.1 PRESENTATION OF THE PROBLEM

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The chassis of a vehicle of the baja type designed for racing BAJA SAE is constructed of steel tubing with a chemical composition with at least 0.18% of carbon, according to the rule of the competition, that restricts the provision of various members and their angles as a matter of safety for the rider. Its manufacturing is done manually so that it is committed to tolerance specified in the project. Figure 7 shows the model study.

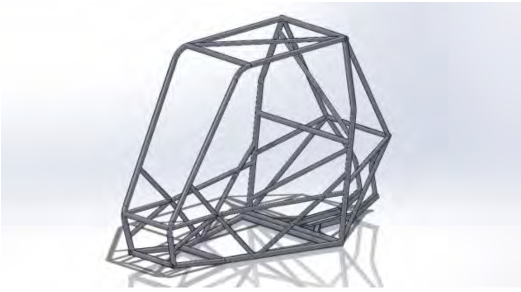

Figure7: Model of chassis

The loads acting on the chassis are basically the weight force and loads of track, from the contact between the tire with the ground when braking, acceleration and suspension inputs, either by scrolling situation curve, as the ride, status difference level, all partially or fully transmitted to the chassis depending on the situation. The last ones are classified as dynamic character, that explain changes in its magnitude and direction over time.

3.2 MATERIAL

To measure the deformations of the chassis uniaxial strain gages were used to steel model PA-06-125AA-120L, Fig. 8, with 120 ohms of electrical resistance provided by Excel Sensors. The signal conditioning gave up in modules and chassis compatible with the sensors, 120ohms, supplied by National Instruments NI9235 model with 8 – channel module and NIcDAQ-9174 chassis to Fig. 9.

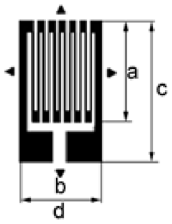

Figure 8 – Strain Gage

a	3,18mm
b	3,18mm
c	6,35mm
d	3,18mm

Figure 9 - Module and chassi

To view and manipulate the data, it was used LabVIEW to be easily handled without programming knowledge, and can be customized according to the need of the operator, creating a virtual measurement, or as the manufacturer calls the virtual instrument, VI. The VI used as shown in Fig.10, and to visualize the deformation profile, the resulting user interface of the VI as show in Fig.11.

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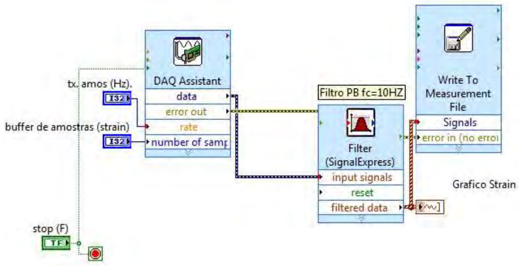

Figure 10 – VI

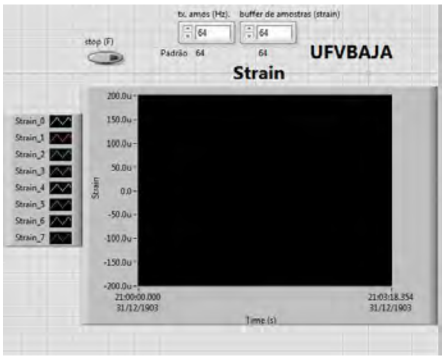

Figure 11 - User interface

3.3 EXPERIMENTAL PROCEDURE

3.3.1 BONDING PROCEDURE

To ensure maximum stability and accuracy in measurement, was adopted by the assembly suggested BALBINOT (2006).

- Clean the surface: The surface to be bonded should be thoroughly cleaned and degreased. You must use the solvent with a soft cloth such as gauze, in order to remove all contaminants such as grease, oil residues.
- Surface Abrasion: Abrasion is performed using abrasives gradual abrasive to achieve the appropriate roughness, in general should be between 0.4 and 6.4 micrometers. In standard CAMI 1200 sand paper can cause a scratch of 6.5 µm in the material.
- Trace the lines: lines are traced as reference for the orientation of the sensors. The marking should be done with a tool that will not scratch or gouge the material to avoid stress concentration.
- Final cleaning: Isopropyl alcohol (cleaning degreaser), is used for remove small surface oxidation. A conditioner and a neutralizer, this last one for neutralize the acidity introduced by conditioning. All this products can be applied with gauze and can be purchased from the supplier of the sensor.
- Handling the Strain: The strain gage should never be directly manipulated with the fingers (due to grease from hands) but with tweezers for proper positioning. The solder terminals should be glued together with gauges. Thus, a neutral tape to be stuck on to both knows to facilitate handling.
- Positioning: strain gage and terminals should be positioned according to the reference line after glued to the tape.
- Bonding: With the tape stuck on one side only, the adhesive sensor should be placed on both surfaces of the structure and the strain gage. Quickly after applying the glue the strain gage must be placed in contact with the surface and with the same gauze should be pressed for about 1 minute against the structure. Subsequently, the tape can be removed and welded terminals.
- Protection: protect the site is interesting in that the strain gage was placed to prevent shock or some other type of problem that will neutralize the sensor. This can be done with silicone (purchased with the supplier strain gage).
- Bondable terminals connection: it is interesting to introduce robustness to the process, so the terminals prevent a pull on the cables reach directly the strain, protecting the system.

3.3.2 EXPERIMENTAL TEST PROCEDURE

A previous CAE analysis environment made it necessary to determine the points of installation of strain gages. In this analysis only vertical and lateral loads from the suspension were considered, show in Fig. 12. The mesh elements were beam type with 664 nodes. The load (5kN) was distributed in the region of the pilot's seat, transmission and drive, with four supports constrains in region of anchoring the shocks. Seven points were selected for analysis, where it had no stress concentration, such as in regions near the weld, holes or creases.

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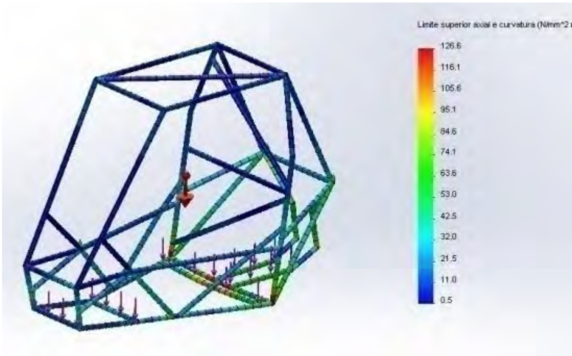

Figure 12 – CAE Analysis

As it is a small vehicle, to board the instrumentation is complicated for measurements in normal use. Thus, a drop test was employed in which the vehicle departed a height of approximately 40 cm from the ground.

When connecting the gauges you can check if they are working properly, sending signal to the acquisition system for the acquisition system is plug and play. In VI you can configure the characteristics of the extensometer, as strength, sensitivity and calibration.

The system was calibrates with the vehicle at rest in the running position, in this configuration all have zero strain tension variation, that is, the signal conditioner applied a voltage in the Wheatstone bridge to cancel the variation of resistance experienced by the strain gage and thereby balancing the bridge. The Wheatstone bridge is frequently used as a mechanism for systems where there are small voltage variations, such as employee, since it presents greater accuracy.

For obtain trace the profile deformation over time continuously, the sampling rate was 800 Hz, the configurable VI, a low pass filter with cutoff frequency of 10Hz.

4. RESULTS

Using the bonding method it was obtained a surface with low roughness and high brightness without any visual mark oxidation or impurity. This process then, did not affect the results of measurements of deformation. Figure 13 shows the result of the bonding procedure.

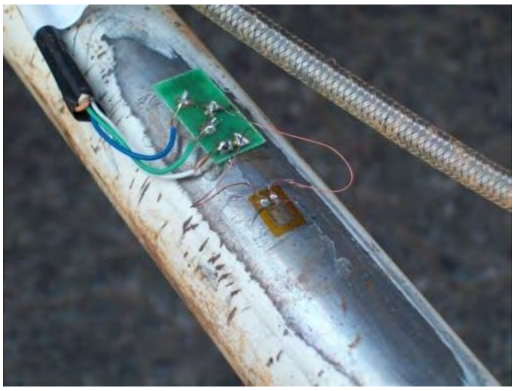

Figure 13–Result of bonding method

The data acquisition system embedded occurred as shown in Fig.14 and 15.

Figure 14 – Data acquisition system embedded

Figure 15 - Embedded system

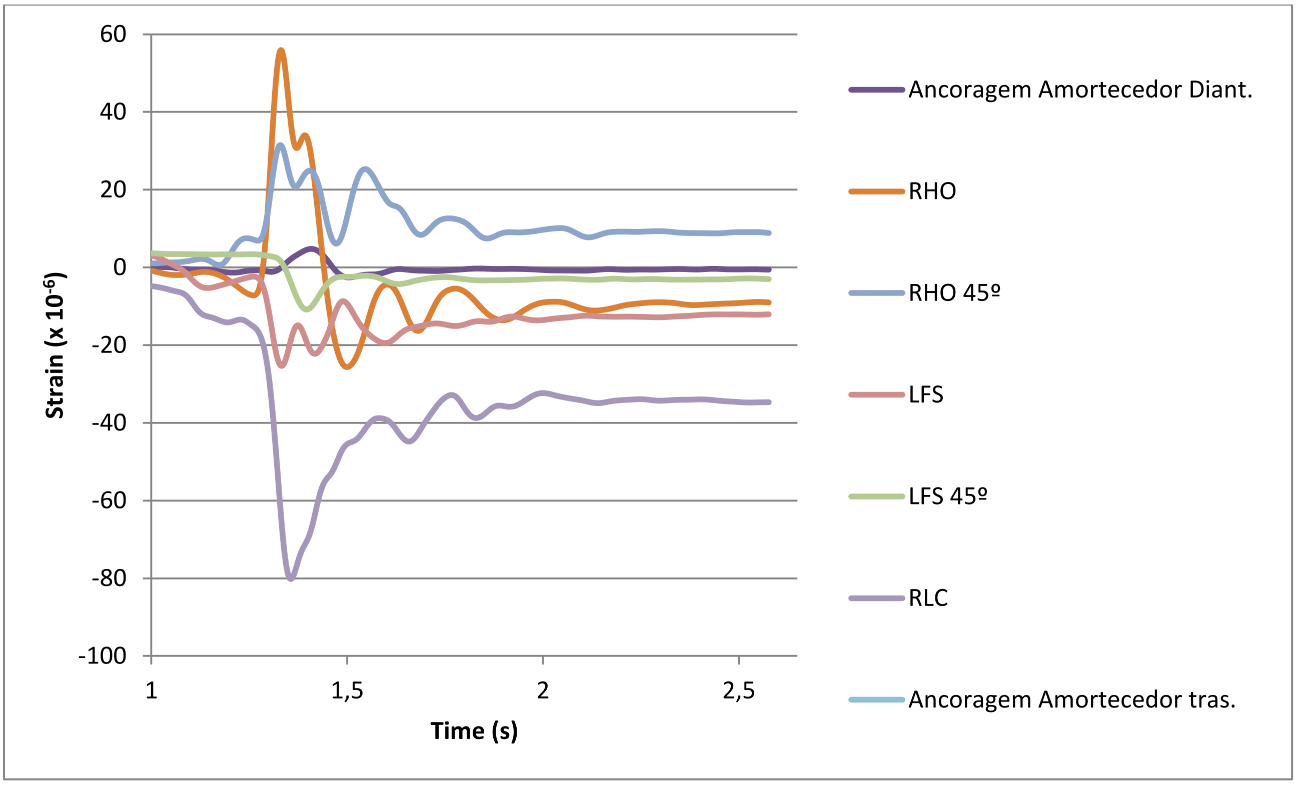

Figure 16 – Time response of the system

The following figure shows members where strain gage were bonded by naming rule.

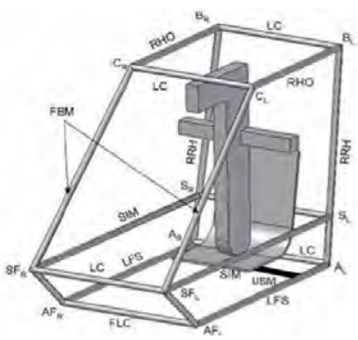

Figure 17 – Available to me members under rule

The calibration of the system is efficient since all points on the deformation near the left zero strain.

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The data acquisition system can show in real time the system response and thereby check for a possible error in the system, even if a sensor has not been calibrated. In systems where measurement accuracy is very important, all the external and internal aspects have to be taken into account.

For the tests performed, the maximum achievable deformation reached 7% of maximum deflection in the elastic material. Such deformation occurred in the pipe named RLC, which is located near the anchorage rear shock. The negative deformation is consistent because the load on the tube is compression.

The system stabilized with nonzero deformation, in this situation the chassis accumulated strain energy, situation expected to occur, remain in a deformed state.

5. CONCLUSIONS

With the implementation of the proposed work, it was possible to acquire and apply the techniques of strain gages, as well as manipulate and calibrate the data acquisition system.

The chassi study showed rigid and safe enough, resulting in low distortion testing conducted, besides suffering a rollover in a real situation that occurred without permanent deformation.

The obtained data will be used to feed future models, and thus decrease the amount of prototypes and the time that they take to be projected.

6. ACKNOWLEDGEMENTS

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