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Structural and physical evaluation of a reinforced beam using strain gauges

N Afanador-Garcia[1], **G Guerrero-Gomez**[2], **and R Gallardo-Amaya**[3]
[1] Civil Engineering Research Group, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia
[2] Grupo de Investigación en Tecnología y Desarrollo en Ingeniería, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia
[3] Grupo de Investigación en Geotecnia y Medio Ambiente, Universidad Francisco de Paula Santander, Seccional Ocaña, Colombia

E-mail: nafanadorg@ufpso.edu.co, gguerrerog@ufpso.edu.co

Abstract. In this research project, the deformations in the longitudinal and transverse reinforcing steel of a reinforced concrete beam with 2ϕ½" were estimated. Additionally, the displacements in the center of the span were measured together with the loads, which generated the cracking of the beam of dimensions 180 mm×240 mm×3100 mm. Displacement were performed using a linear variable displacement transducer, and strain gauges were used to measure deformations. Finally, the applied load's measurements were obtained with a load cell Pinzuar/Model-100/20T equipment. The physical-mechanical properties of the concrete used were determined through compressive strength tests at 28 days and modulus of elasticity. For this purpose, a load-bearing frame was used to support the beam at three points for load application. The data was collected directly on the Quantum/X2 equipment and analyzed with the help of the Catman/AP software. The maximum deformations found in the bending test at three points in the reinforced concrete beam were not greater than 8483 μm/mm, presenting a failure in the center of the beam due to the creep of the tensile steel for a maximum load of 3115 Kg. Finally, the physical behavior of the reinforced concrete beam with applying a load allows evaluating and optimizing this kind of systems.

1. Introduction

Strain gauges are piezoresistive sensors, manufactured with metallic or semiconductor materials (silicon or germanium). The main objective of this type of sensors is to determine the deformations in any direction or sense in a specific point of a structure that can be metallic, non-metallic or concrete, considering the effect of the electrical resistance that the strain gauge has with a micro-measurement, which works under the effect of Hooke's law, which states that the deformation of an elastic material is directly proportional to the applied normal force [1]. Thus, strain gauges are widely used in civil engineering because it is possible to predict the deformations, stresses, and cracks generated in structural elements of any material and type of element (beams, walls, masonry units, among others) [2].

Considering the literature review, several studies have addressed the analysis of beams of different materials in order to determine the loads where the material generates creep and thus the initiation and propagation of cracks that induce the failure of the material and/or structure. According to Masri, *et al.* [3], fiber optic sensors or strain gauges integrated to structures provide valuable information

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about the state of deformations of different materials when subjected to loads through monitoring during the test. Moreno-Robles and García [4] determined the loads applied to a train rail using strain gauges. To validate the results and the data obtained correctly, the authors performed a 3D numerical model using FLAC3D software [5]. The results showed that the strain gauges must be separated at least 50 mm from the point where the load is applied to obtain results that match the real values. Huang, *et al.* [6] evaluated the properties of concrete based on the optical technique automatic digital image. correlation (ADIC) using strain gauges. This correlation process helps to automatically determine the deformation of concrete in real time without the need for visual inspection.

The results demonstrated that it is possible to propose a new optical strain gauge to monitor in real time the strain and determine the compressive modulus of elasticity of concrete based on the ADIC model, being an accurate, cost-effective, and reliable method. Kim, *et al.* [7] developed a new silicon strain gauge using microelectromechanical systems (MEMS) technology. The results showed that the proposed gauge minimizes the position change in measurement and improves the bond strength thus improving the sensor performance and in turn the manufacturing cost. Payo and Feliu [8] designed a sensor system to determine real-time 3D deformations of flexible beams using strain gauges. The results showed that the designed system meets the specifications to obtain quality measurements that contribute to the analysis of the results with few computational requirements. Finally, Chen, *et al.* [9] developed a strain gauge design to obtain the strain distribution in a region of a structure. The results show that the proposed design is reliable and robust for different industrial applications.

Considering the above, the present research work aims to estimate the deformations in the longitudinal and transverse reinforcing steel of a reinforced concrete beam with 2 ½" up and down of a beam of dimensions 180 mm×240 mm×3100 mm using 10/120-CLY41-3L-0.5M strain gauges. The assembly was carried out on a load frame with a capacity of 50 t in compression and 30 t in tension, and the data were extracted using Quantum/X2 equipment with the help of Catman/AP software [10].

2. Methodology and materials

Strain gauges are widely used to determine length changes in different parts of a structure. Figure 1 shown the typical geometry of a strain gauges used to the developed of different studies in reinforced concrete (beams) [11]. The commercial stain gauges had the following parameters, type 10/120-CLY41-3L-0.5M, resistance 120 Ω, K gauge of 2.11, and transverse sensitivity 0.2%. Notice that the resistance of the strain change with the gauge deformation [11].

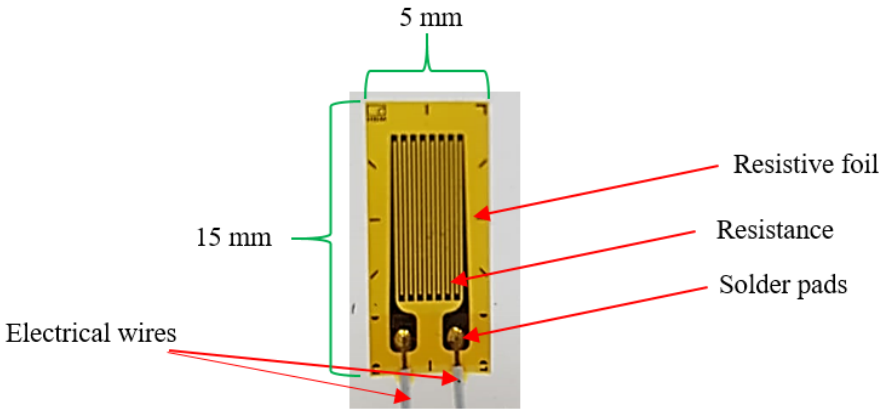


Figure 1. Main characteristics of a strain gauge.

The installation of the gauge on the rods, it is very important to have a smooth and clean surface that allows a proper installation and adhesion to ensure a correct measurement of the values that can be obtained during the test [12]; the gauge must be well installed to ensure adhesion with the surface, and for this, the procedure described in Figure 2 was considered.

Considering the above, the 180 mm×240 mm×3100 mm reinforced concrete beam was fabricated considering the configuration shown in Figure 3; the rods used were 2 ½ inch rods top and bottom with 9 $^{3}/_{8}$ inch stirrups every 60 mm and in the center every 120 mm. The strain gauges were installed considering the steps in Figure 2, and located in the beam as detailed in the red circles, one pair at the end, and another pair in the center of the beam where the maximum stress and deformation is generated due to the load applied during the development of the test [13].

From step 4, presented in Figure 2 (set-up and execution of the test), the process for the execution of the laboratory test; initially, a load frame was used where the instrumented beam was supported to perform the three-point bending test. Subsequently, after the application of the gradual load at the midpoint of the beam, using a Pinzuar/Model-100/20T load cell, deflections were generated, which were obtained with the help of the REP/LDT 50 mm and 100 mm linear variable displacement transducer (LVDT) equipment with 2 mV/V output; the data were continuously recorded in the Quantum/X2 equipment and later analyzed in the Catman/AP software [10].

Setting the direction of the strain gauges on the rod required a study to determine the point to be evaluated, the main coordinate planes and the type of mechanical stress (tensile or compressive) to which the structure (beam) will be subjected; there are two types of applications that gages can have. The first one is because of the variable to be found, for example the deformation, which is intermediate; the second is the state to be known (tension or compression). Strain gauges are useful for all those situations in which it is necessary to find stresses and strains in structures that obey Hooke's law.

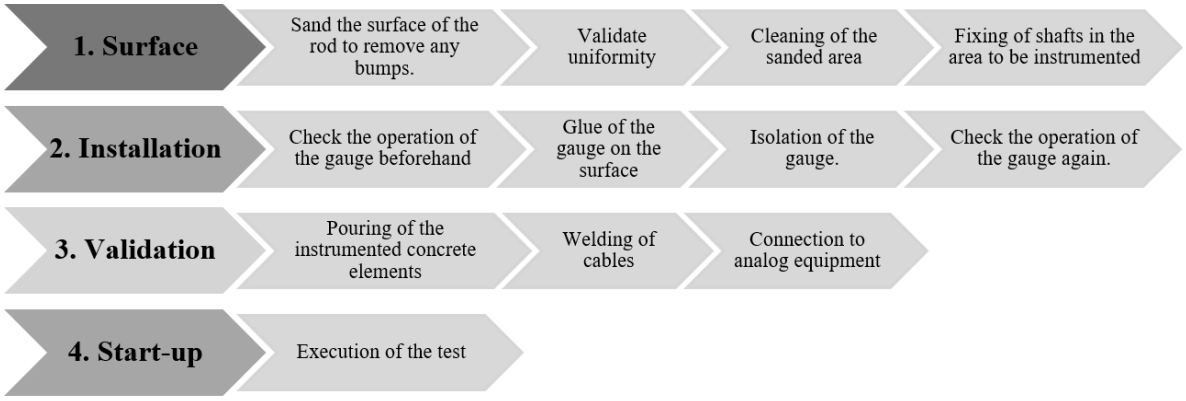


Figure 2. Guidelines applied to develop tests.

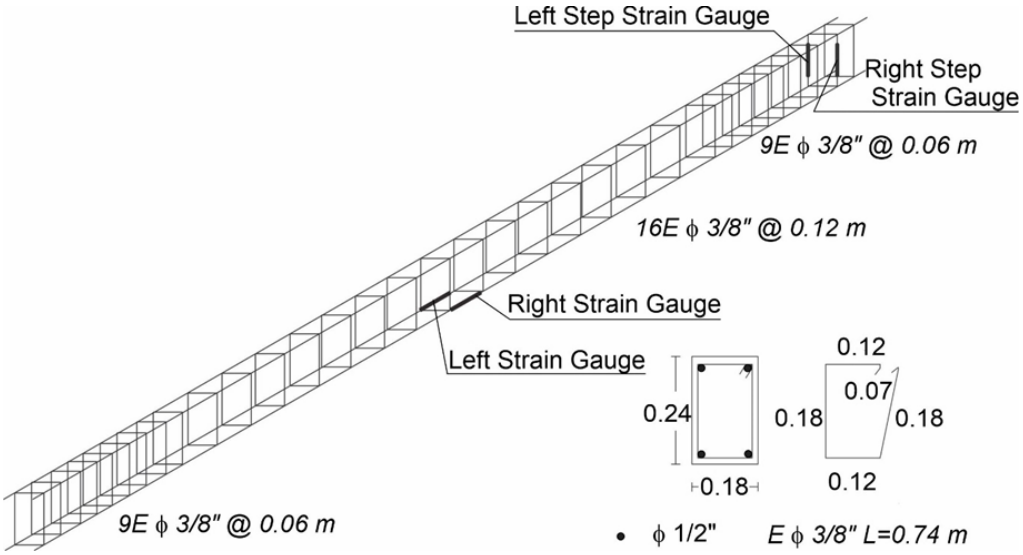


Figure 3. Geometry and specifications of the instrumented beam.

3. Results and discussions

In this section, the main results collected from the flexural test on a beam with strain gauges are reported, considering from the properties of the concrete until the analysis of the results. The parameters and physical-mechanical properties using of the concrete used for the manufacture of beams reinforced with rebar are as follows: dosage 1:2:3, compressive strength at 28 days = 9.05 MPa, slump 11.5 mm, density 2354.67 Kg/m3, and modulus of elasticity 1.00 MPa.

The reinforced concrete beam with the strain gauges incorporated in the rods was instrumented with its respective mounting in the load frame, as shown in Figure 4; the beam with its respective connections and the load cell, whose information during the development of the test was collected as detailed in Figure 4. The configuration used for the evaluation of the reinforced beam in the three-point bending test, using strain gauges, is similar to that reported by [14-16].

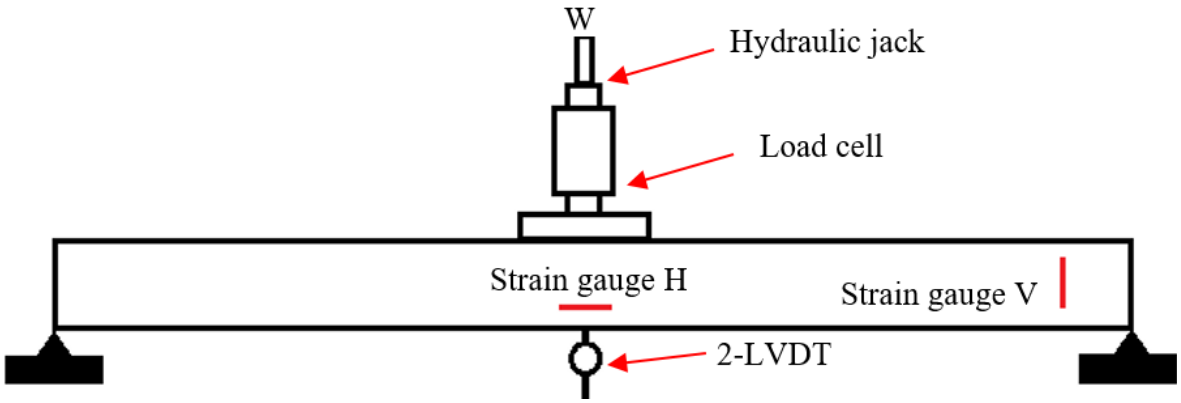


Figure 4. Schematic diagram of flexural test in the reinforced beam.

Once the flexural test on the beam was completed, the results were compiled and analyzed in the Catman/AP software [10], obtaining the results shown in Figure 5. Figure 5(a) shows the behavior of the load applied using a hydraulic jack and measured through the load cell, with a load speed of approximately 170 Kg/min, which increased up to 3200 Kg. This is the instant at which the reinforcing steel creep and the flexural failure of the reinforced concrete beam occurred. Note that, t is the test time, P is the applied load, Δ is the displacements and Ɛ are the deformation.

Figure 5(b) indicates the behavior of the average deflection, that is, the average value for the two LVDTs located in the center of the beam, in order to avoid distortion in the beam deflection; the observed behavior indicates a small load adjustment zone in the beam due to a small preload. The deflection-time relationship is linear, with a deflection rate of 0.020 mm/s, after a load equal to 180 Kg is applied.

Figure 5(c) indicates the deflection behavior of the average longitudinal reinforcement, that is, the average of the two gauges installed on the 2 ½" steel bars located at the bottom of the beam, in order to avoid distortion in the deformation; the behavior is linear up to the theoretical creep deformation of 0.0021, while the experimental creep deformation was 0.0027. Figure 5(d) shows how the average deformation varies over time in a stirrup located 60 mm from the beam support, the strain gauges located on the vertical sides of the stirrup are intended to avoid distortion in the deformation.

Due to the effect of the load applied on the beam at the center of the span, this element failed by creep of the bottom steel, generating the presence of cracks from the bottom to the top of the beam as shown in Figure 6. It was observed that the loads that generated cracking were between 255 Kg and 3115 Kg, the latter when the beam failed.

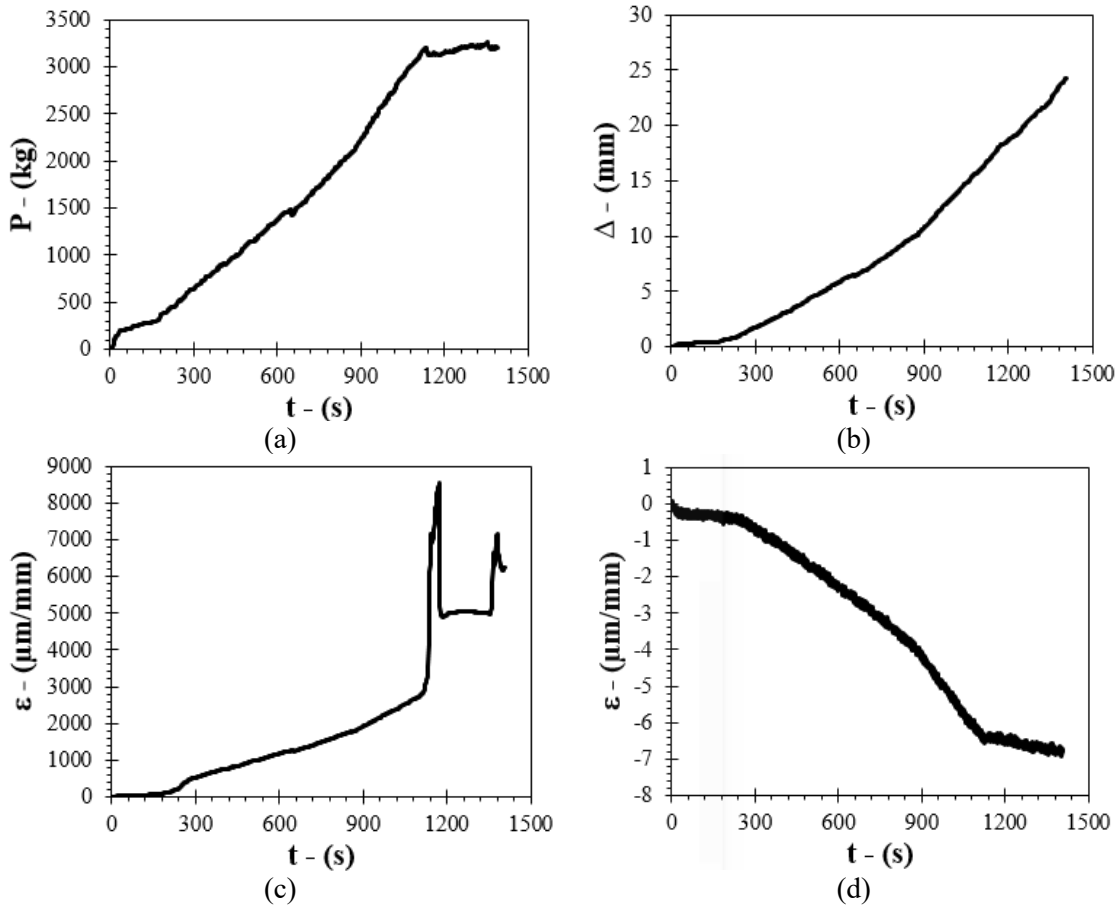


Figure 5. Experimental results obtained from Catman/AP software; (a) behavior of the applied load, (b) average vertical displacement at the center of the beam, (c) average deformation of longitudinal reinforcement, (d) average deformation of transverse reinforcement.

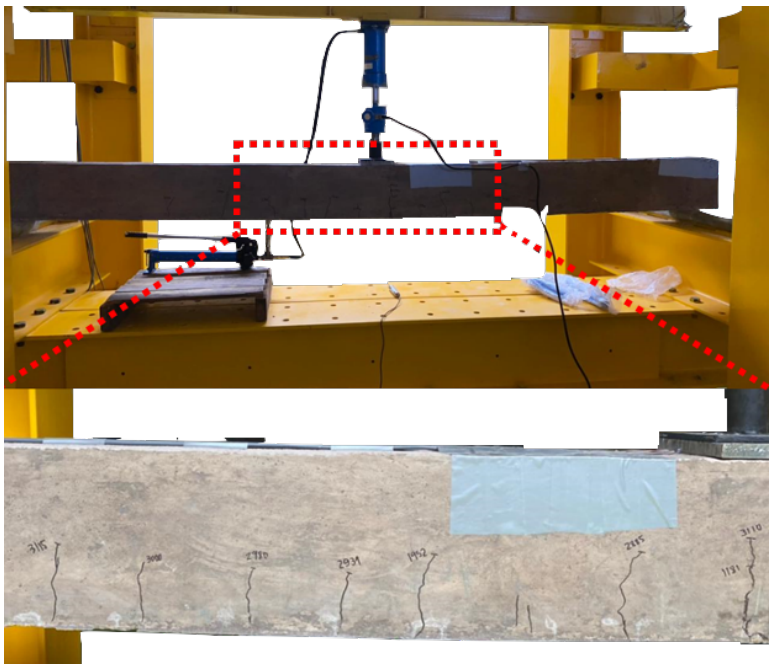


Figure 6. Cracks developed under the applied load.

4. Conclusions

It was established that the theoretical statement that creep occurs in a smoothed form is not true; there is a rearrangement of the grains that make up the reinforcing bars at the moment of creep and there is a small jump in creep deformation for small variations in load. After steel creep, there is a relaxation zone where the deformation increases without load increase.

The maximum deformations found in the bending test at three points in the reinforced concrete beam were not greater than 8350 μm/mm, presenting a failure in the center of the beam due to the creep of the tensile steel for a maximum load of 3115 Kg. From the analysis developed for the cracks generated under the applied load it can be seen that there are no significant shear cracks, due to the small separation between stirrups that does not allow the shear cracking to propagate, contrary to that presented by bending that they distribute along and above of the beam.

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