

## **FYBER OPTIC STRAIN GAGES FOR STRESS ANALYSIS BY MEANS OF THE HOLE DRILLING TECHNIQUE**

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### **Abstract**

The article deals about the application of the Hole-Drilling technique on structural elements of the architectural heritage constructions by using eight fiber optic strain gages. The objective of the research is the on site deduction of the stress state on stone masonry of the Architectural Heritage constructions. Hole Drilling method is a Minor Destructive Testing (MDT) giving information about the Principal Stresses of the local stress state around the measured zone and, in consequence, it favours the estimation of the stresses associated with a certain direction, for example the vertical stress of a stone masonry element. Fiber optic technology allows the storage of the strains in the strain gages even when the unit of measure is temporary not connected. Thus it will be able monitoring the stress measurements as time function.

The tests carried out have compared the applied loads in laboratory machine with the results obtained by Hole Drilling technique through fiber optic strain gages. Until now only resistive strain gages have been used. In this sense the contribution is innovative with an evident advance towards the complete structural characterisation of stone masonry structural elements.

*Keywords: Hole Drilling, stress measurements, cultural heritage, masonry*

### **1 Introduction**

Hole Drilling Technique has been widely applied in previous works to obtain the existent stresses in the structural elements in constructions of the Cultural Heritage [1,2,3,4,5]. The method is based on the strains caught by resistive strain gages (RSG) glued over the element. This kind of strain gages (made of copper) allows only one experimental procedure. Once the measurement has finished is not possible to repeat the reading of strains in the strain gages. Fiber optics sensors can store the strains for successive readings, being able to generate a monitoring process. This is the reason for which the authors try to analyze the results obtained by means of Hole Drilling technique by using a set of fiber optics strain gages (FOSG).

## 2 Brief description of the Hole Drilling technique

The technique is based on the ASTM Standard E837-95 [6,7] being applied since 1992 in stone masonry. The restrictions of the technique are explained in this Standard in detail. Three strain gages are sufficient for the deduction of a state of stresses in bi-dimensional situations. Nevertheless, usually eight strain gages are glued over a stone block in order to avoid experimental errors. The experimental procedure includes several steps with a transcendental influence for the final results. The surface is slightly polished in order to glue the strain gages over a smooth substrate. The strain gages are carefully glued over a circumference of diameter 4 cm with its centre identified as best as possible. The test begins recording the strains during 60 minutes at least before drilling. This aims at understanding the fluctuations around the zero strain. From previous experience the test is considered valid when these fluctuations do not exceed 5  $\mu\text{m/m}$ . After the strains are stabilised, a hole of 3.2 cm depth with 3.6 cm diameter is drilled. The centre of the strain gages position and the centre of drill have to be as coincident as possible. The ultimate experimental step consists in recording the strains measured by the strain gages each 5 minutes during 120 minutes at least. According the ASTM Standard E837-95 the strains  $\varepsilon_1$ ,  $\varepsilon_2$  and  $\varepsilon_3$  measured by three strain gages “1”, “2” and “3” (fig. 1) respectively are related with the stresses through the following expressions:

$$\sigma_{max} = \frac{\varepsilon_1 + \varepsilon_3}{A} - \frac{\sqrt{(\varepsilon_3 - \varepsilon_1)^2 + (\varepsilon_3 + \varepsilon_1 - 2\varepsilon_2)^2}}{B} \quad (1)$$

$$\sigma_{min} = \frac{\varepsilon_1 + \varepsilon_3}{A} + \frac{\sqrt{(\varepsilon_3 - \varepsilon_1)^2 + (\varepsilon_3 + \varepsilon_1 - 2\varepsilon_2)^2}}{B} \quad (2)$$

$$\beta = \frac{1}{2} \arctan\left(\frac{\varepsilon_3 + \varepsilon_1 - 2\varepsilon_2}{\varepsilon_3 - \varepsilon_1}\right) \quad (3)$$

where  $\varepsilon_1$ ,  $\varepsilon_2$  and  $\varepsilon_3$  are the strains recorded respectively at  $0^\circ$ ,  $225^\circ$  and  $90^\circ$  with a direction of reference.  $\sigma_{max}$  and  $\sigma_{min}$  are the maximum and minimum principal stresses respectively and  $\beta$  the angle (measured clockwise) of  $\sigma_{max}$  with the direction of  $\varepsilon_1$  (or  $\sigma_{min}$  with the direction of  $\varepsilon_3$ ). From these values it is possible to deduce the vertical stresses ( $\sigma_{vert}$ ).

The constants A and B are related to the Poisson Coefficient ( $\nu$ ), the Young Modulus (E) and two dimensionless parameters “a” and “b” that include the geometrical conditions of the test. Standard ASTM E837-95 establishes for “a” and “b” the values 0.2 and 0.5 respectively. Constants A and B can be deduced by means of the following expressions:

$$A = -4 \left( \frac{1+\nu}{2E} \right) a$$

$$B = -4 \left( \frac{1}{2E} \right) b$$
(4)

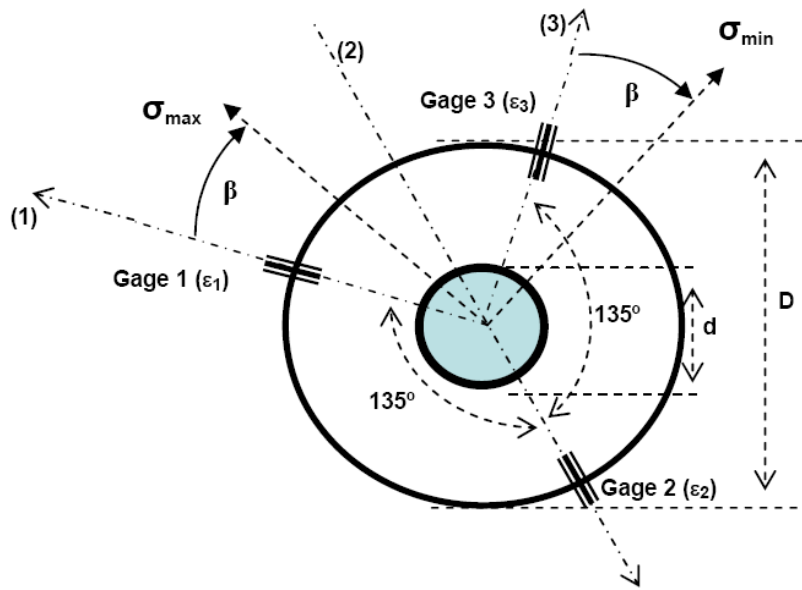


Figure 1: Layout of the geometry for the Hole Drilling Technique. “D” is the diameter of the circumference of the strain gages whereas “d” is the diameter of the drill. The symbols (1), (2) and (3) shows the directions of the strain gages 1, 2 and 3.

The value of Young Modulus (E) is obtained from specific tests on stone samples with a composition similar to the stone material used in the case studies. Alternatively this value is taken from library. The Poisson Coefficient ( $\nu$ ) is considered to be 0.25 in agreement with previous experience on sandstone [9].

The procedure above explained has been always applied in normal works by using RSG with a length of 6 mm.

### 3 Laboratory tests

The experimental works have been carried out over a stone block (35 cm x 35 cm x 31 cm). Hole Drilling procedure has been performed in order to compare

the stresses thus obtained with the applied load in test machine at laboratory. The results obtained by two kinds of strain gages have been compared after loading the stone block under a known load. The strain gages have been glued in two opposite sides. Eight RSG have been placed in a side whereas eight FOSG have been glued in the opposite side (fig 2 and 3). Table 1 shows the load process over the sample and the strains recorded in a vertical strain gage of the two kind of material. Hole Drilling procedure has been performed in both sides at the final load (17 Mpa). The experimental conditions for RSG follow the scheme above mentioned. The diameter of the FOSG circumference (“D” in fig. 1) has to be 14 mm due to both their size (15 mm length) and the requirements of the connection wires management. This new value for “D” affects the value of the constants “a” and “b”. In this case ASTM E837-95 establishes for “a” and “b” the values 0.11 and 0.28 respectively.

The results here described have been obtained from strains recorded by the strain gages at 180° (vertical direction), at 90° (horizontal direction) and at 315° (fig. 2 and 3). The other five strain gages in each side have been saved for other experimental works in a different research field.

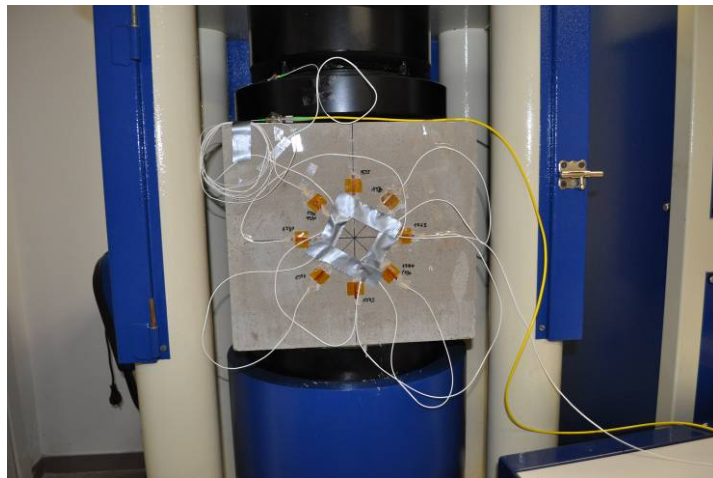


Figure 2. FPSG placed over a side of the sample

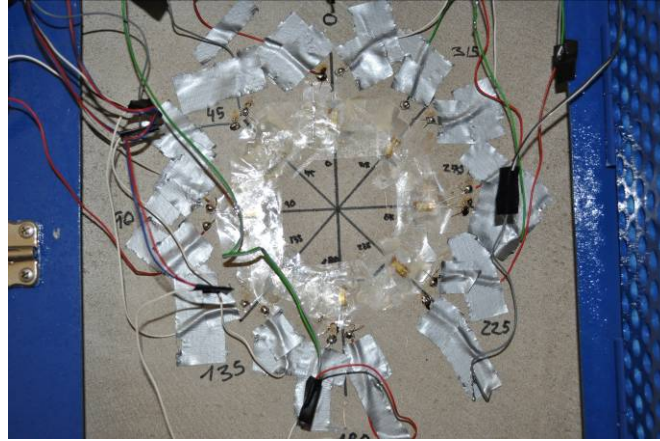


Figure 3. RSG placed over a side of the sample

Table 1. Values of the applied loads and the strains recorded in vertical strain gages

| Applied stresses (Mpa) | Strains in vertical RSG (microns/meter) | Strains in vertical FOSG (microns/meter) |
|------------------------|---|--|
| 0                      | 0                                       | 0  |
| 4                      | 46                                      | 22                                       |
| 8,06                   | 146                                     | 260                                      |
| 12,11                  | 256                                     | 450                                      |
| 17                     | 390                                     | 700                                      |

#### 4 Results

From library the value of Young Modulus (E) of the loaded rock (sandstone) has to be near 30000 Mpa. The results shown in Table 1 allow an estimation of two values for Young Modulus of the sample depending of the strain gages classes. Selecting the last three steps of load process it is obtained 36000 Mpa for RSG and 18000 Mpa for FOSG. Fig. 4 and 5 shows the strains recorded by using Hole Drilling technique in both sides maintaining the sample loaded at 17 Mpa. Table 2 shows the stresses obtained from these values. The strains for Hole Drilling analysis are the differences between the initial strains (sample loaded) and the final strains after extracting material by drilling.

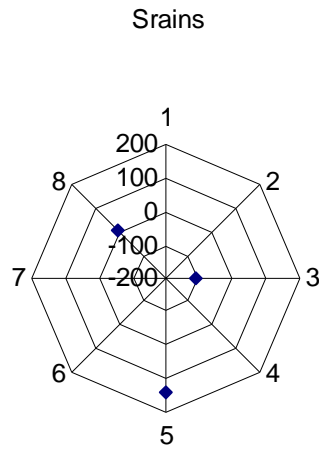


Figure 4. Strains recorded for Hole Drilling technique by FOSG. The initial strains at 17 Mpa relax after drilling.

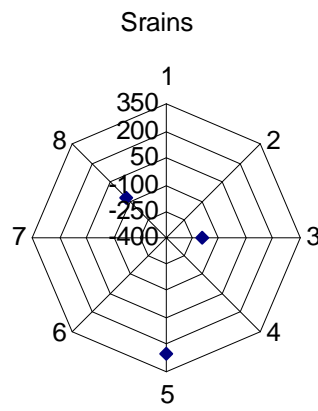


Figure 5. Strains recorded for Hole Drilling technique by RSG. The initial strains at 17 Mpa relax after drilling.

Table 2. Stresses deduced according Hole Drilling technique for both kinds of strain gages. The sample is loaded under 17 Mpa.

| Strains for FOSG (microns/meter) |       | Strains for RSG (microns/meter) |       |
|----------------------------------|-------|---------------------------------|-------|
| 180° (E1)                        | 138   | 180° (E1)                       | 244   |
| 90° (E3)                         | - 113 | 90° (E3)                        | - 200 |
| 315° (E2)                        | 0     | 315° (E2)                       | - 92  |
| Vertical stress (Mpa) for FOSG   |       | Vertical stress (Mpa) for RSG   |       |
| - 11                             |       | - 17                            |       |

## 5 Conclusions

The results obtained by using the two kinds of strain gages are absolutely different. The strains recorded by the two kinds of strain gages are different under same load (Table 1). The same conclusion can be deduced from the stresses obtained by means of Hole Drilling technique (Table 2). RSG have been widely used in previous works having a great experience about their applications and limits. FOSG have been elaborated exclusively for this research. It is well known that the fiber optics sensors for strain or displacement measurements are widely proven. Nevertheless the obtained results for the FOSG are at the moment not considered like certain. The authors have not achieved to discover the reason for this trouble. Same result was detected in a similar work performed some months ago. It is foreseen the repetition of the tests with a careful control of the experimental parameters as detailed as possible.

## References

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