Health monitoring of civil engineering infrastructures with optical fiber sensors

Paulo Antunes, Hugo Lima, Humberto Varum, Paulo André

Abstract— Structural health monitoring is a fundamental tool to guaranty the civil infrastructure lifetime. In this paper, the monitoring of an adobe structure with optical fiber sensors is reported. Static and dynamic measurements were made during a destructive test on a full-scale wall, with an optical fiber accelerometer and a network of thirteen multiplexed displacement sensors. The measured values shown a decrease of 47.8 % in the first natural frequency value, between the initial situation (structure undamaged) and after the cyclic test (structure damaged). The results show very good agreement (maximum relative error in terms of structural frequency of 2.08 %) between the results obtained using electronic sensing technology and the optical sensing technology.

Index Terms— **Optical fibers Sensors, Adobe construction**

I. Introduction

Civil engineering works require structural health monitoring (SHM) to predict their structural health during lifetime [1,2]. Optical fiber sensors are among the most promising sensing technologies due to the advantages over traditional electronic sensing. Among a wide variety of optical sensors, FBG based acceleration sensors and deformation sensors can be applied in SHM of civil engineering structures [1]. Since FBG sensors are an all-in-fiber technology, they take advantage of the optical fiber properties, presenting also advantages over traditional electronic sensors due to the possibility to multiplex a large number of different sensors into the same optical fiber, reducing the need for multiple and heavy cabling used in traditional electronic sensing. These sensors may provide an effective solution to measure simultaneously static and dynamic parameters at lower prices, presenting advantages in comparison with another type of optical sensors. In fact, due to the high response speed, FBGs can also be used in dynamic measurements of acceleration, in order to derive the structures eigenfrequencies [1]. This type of information could be useful to infer about the structures integrity, since the values of the structure eigenfrequency are directly related with the global structure stiffness.

In the littoral centre region of Portugal, construction with earth is still a very common practice. In Aveiro district, adobe blocks are abundant both in rural and urban buildings, many of which are of recognized cultural, historical, and architectonic value. A great number of the existing adobe constructions present pronounced structural damage resulting from lack of maintenance [3]. Therefore, it is important to investigate the structural behavior of this type of constructions, particularly in what regards the seismic safety and to develop efficient and compatible strengthening solutions.

In this work, the monitoring, with optical sensors, of a full-scale adobe wall during a destructive test is described. This structural trial allows to demonstrate the feasibility of applying static and dynamic optical FBG sensors to study the response and behavior of a civil engineering infrastructure, namely for a traditional constructive system with adobe blocks.

II. Procedure

The displacement sensors adopted in the adobe structure testing utilizes fiber Bragg gratings attached to two supports, one rigid fixed and the other adjustable.

Further details on the accelerometer structure and design can be found in reference [1]. The sensors were placed in the adobe structure according to the scheme outlined in Fig. 1.

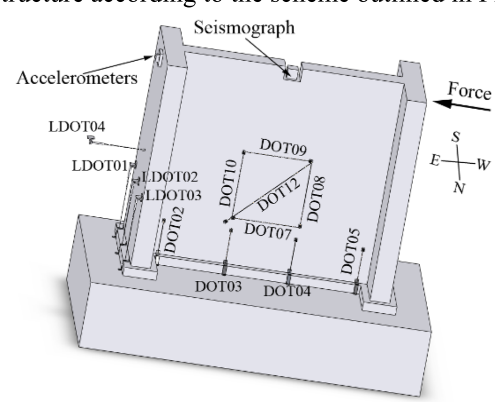

Fig. 1. Adobe wall schematics with indication of the sensors location.

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Paulo Antunes, Hugo Lima and P. S. B. André are with Departamento de Física da Universidade de Aveiro and Instituto de Telecomunicações, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal (phone: +351 234370356; fax: +351 234378197; e-mail: pantunes@ua.pt, hlima@ua.pt, paulo.andre@ua.pt).

H. Varum is with Departamento de Engenharia Civil da Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal (e-mail: hvarum@ua.pt).

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The FBGs produced and used in this study were printed in photosensitive single mode fiber (FiberCore PS1250/1500) with a 248 nm KrF laser, using the phase mask technique. They have a 3 mm length and an average optical rejection of 25 dB and each one was written with a different Bragg wavelength.

The horizontal forces were imposed by a hydraulic jack fixed on the West face of the wall, along the direction West→East. The hydraulic jack, was placed at a height of 2.5 m and was fixed to a reaction-wall lying West of the adobe wall.

III. Results

During the test, static deformation evolution due to the application of cyclic horizontal load was measured. Dynamic measurements were carried out in different states of degradation of the wall during the destructive test, allowing to obtain the first natural frequency evolution with the structural stiffness.

In Fig. 2 the data gathered from displacement sensor DOT05 placed at the base of the N face of the wall as well as the external force history. From the analyses of the network all sensors it is observed a lift of the structure on the side where the load is applied and a contraction of the opposite side. Given the "I" shape of the wall, this result is also expected.

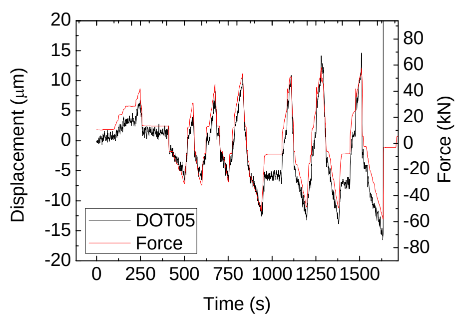

Fig. 2. Displacement evolution measured at sensor DOT05 placed at the base of the N face of the wall and applied force history.

The implemented acceleration optical sensor was used in dynamic measurements in the adobe structure in order to derive its natural frequency, simultaneously with an electronic accelerometer and a seismograph. The accelerometers, optical and electronic, were placed on the face E at 20 cm from the top, with its sensitive axis aligned with the direction W-E. In turn, the seismograph was located in a central area, at the top of the wall, being sensitive to acceleration in three directions. With the three sensors mentioned above readings of the acceleration data over time were made, applying the dynamic impulses on the wall in the direction of W-E, as excitation. This procedure was repeated for several states of damage, before and during the destructive cyclic test. For each dynamic test, the natural frequency was obtained by applying a FFT to the acceleration data over time. The value of the first natural frequency of the wall is observed in Fig 3, for dynamic test 5.

The first natural frequencies of the wall, estimated from the accelerations measured in different dynamic tests, are summarized in Table I.

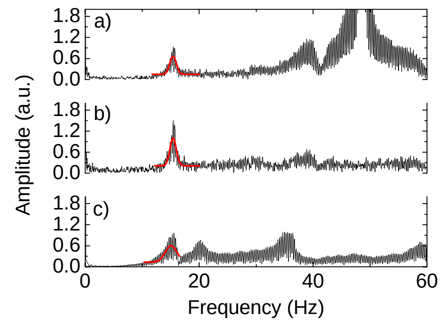

Fig. 3. Frequency spectrum obtained by Fourier transform of the acceleration data over time in the dynamic test 5: (a) Optical Accelerometer, (b) Electronic Accelerometer and (c) Seismograph.

Table I

First natural frequency of the adobe wall, estimated from the accelerations and relative error of the natural frequency

	Frequency (Hz)			
Ref. dynamic test	Optic	Electronic	Seismograph	Error (%)
1	23.08	22.79	22.89	1.05
2	22.41	22.11	22.06	1.47
3	21.88	21.32	21.55	2.08
4	17.94	17.67	17.79	1.18
5	15.41	15.43	15.07	1.05

From the data in Table 1, it is possible to deduce the good performance of the optical acceleration sensor implemented. The measured values shown a decrease of 47.8 % in the first natural frequency value, between the initial situation (structure undamaged) and after the cyclic test (structure damaged).

IV. Conclusions

A network of thirteen displacement sensors was implemented and successfully interrogated, allowing to monitor a destructive test conducted on an abode wall. The first natural frequency of the structure was successfully determined using the optical sensor with a maximum relative error of 2.08% when compared with the reference sensors. There is a decrease in the natural frequency of the structure with the damage propagation during the destructive test. The obtained results demonstrate that the optical fiber sensors had the capacity to monitor this large scale tests.

References

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