INNOVATIVE HIGH RESOLUTION 3-D VISION AND OPTICAL FIBER SENSORS FOR DATA ACQUISITION DURING EXPERIMENTAL EARTHQUAKE TESTS

G. De Canio* , M. Caponero*, A. Colucci*, I. Roselli*

**ENEA Centro Ricerche Casaccia*
Email: decanio@casaccia.enea.it

ABSTRACT

In this paper is described an innovative High resolution 3-D optical movement detection and analysis to track the dynamic displacement of the selected points of masonry and concrete buildings mock-up during the dynamic laboratory tests of natural (earthquake) and artificial (mechanical, aerospace) induced vibrations by the shake table earthquake test facilities at the ENEA Casaccia Research Center, Rome, Italy. Twelve high resolution (up to 4MPixel) Infrared Cameras have been used to measure accurate 3-D positions of hundred of markers placed on the structure during the seismic tests. The innovative monitoring technique allows measuring 3 axial absolute displacements with easy and fast test set-up, high accuracy and the possibility to link the 3D-motion time histories of the tracked markers with CAD drawings of the structure and validate the FE models in real time experimental data assimilation. The new monitoring system have been tested during a shaking table experiment on a masonry building representative of the historical houses still used for civil habitation in Italy. Moreover, optical fiber displacement sensors and Bragg Grating Sensors have been applied for static and dynamic strain data acquisition within an extensive experimental investigation on shaking table carried out for the TREMA project (Technologies for the Reduction of seismic Effects on Architectural Manu facts) on a new system for the seismic retrofit of R/C frames.

KEYWORDS: seismic tests, shaking table, 3D-Vision, FBG, distribuited laboratory

1. INTRODUCTION

The main experimental facilities for vibration and seismic tests at the ENEA- Physical Technologies and new Materials laboratories of the Casaccia Research Center of Rome, Italy, consist of two electrodynamics shakers and two high performance seismic tables for three axial seismic tests of structures up to 10 ton mass and 3g acceleration applied at the Center of Gravity at 1m from the base table.

Table 1.1 principal characteristics of the laboratory facilities

	Table 1 (Master)	**Table 2**	**Shaker 1**	**Shaker 2**
Table size	4m x 4m	2m x 2m	1.5m x 1.5m	0.6m x 0.6 m
Degree of Freedom	6 DOF	6 DOF	1	1
Frequency range	0-50 Hz	0-100 Hz	5-2000 Hz	5-2000 Hz
Acceleration	3g peak	5g peak	125g (0-peak)	100g (0-peak)
Velocity	0.5 m/s (0-peak)	1 m/s (0-peak)	2 m/s (0-peak)	1.2 m/s (0-peak)
Displacement	0.25 m (0-peak)	0.30 m (0-peak)	0.025m (peak-peak)	0.025m (peak-peak)
mass and G.C. height for rigid specimen	10 ton mass 1m c.g height	1 ton mass 1 m c.g.height	145 KN Force	27 KN Force

Figure 1 ENEA R.C. Casaccia Structural Dynamics and Vibration Control Laboratory

The shaking table tests can reproduce the real stress-strain field in the structures due to the dynamic loads induced by wind, traffic and earthquakes. The seismic activities of the laboratory are principally devoted to the experimental analysis of innovative systems for the seismic isolation and retrofitting of civil, industrial, and historical buildings, together with the seismic tests of sub-structures and scaled mock-ups, in order to evaluate their dynamic behavior, the isolation/dissipation performance of the anti seismic devices and the failure modes of the building's structural parts.

2. OBJECT TRACKING AND 3D-VISION

The Object Tracking and 3-D optical movement detection and analysis have been experimented to track the motion during the low frequency (up to 30Hz) vibrations typical of the shake table earthquake tests. High resolution Infrared Cameras have used to measure accurate 3-D positions of markers placed on the building during the seismic tests. To detect the motion, each marker must be viewed at list by 2 cameras in order to calculate its 3D coordinates with respect the absolute reference. The measure of the displacements is a crucial task for the numerical and experimental studies in structural dynamics, especially within the displacement based approach in seismic design and calculations.

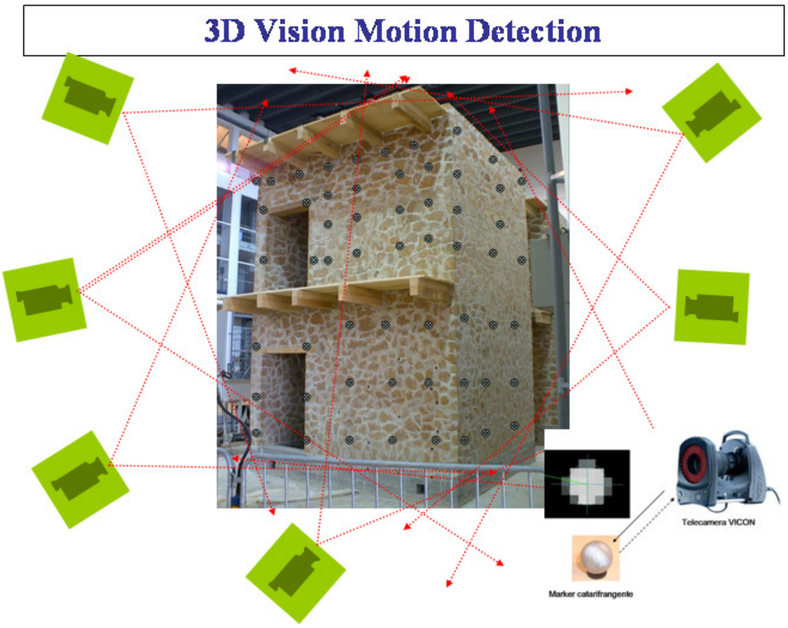

Figure 2 position of the camera to detect the motion of the markers

The first step of the marker displacement data analysis consists in the time histories filtering using a Savitzky-Golay polynomial filter (Sgfilter). Successively, after double derivative to calculate the acceleration, a band Pass filter is applied to the acceleration time history. The choice of the most appropriate filtering parameters has been made comparing the results from different combinations of the parameters. E.G. the figure 3 shows the effect of the SGfilter with different polynomial degree and same windowing width.

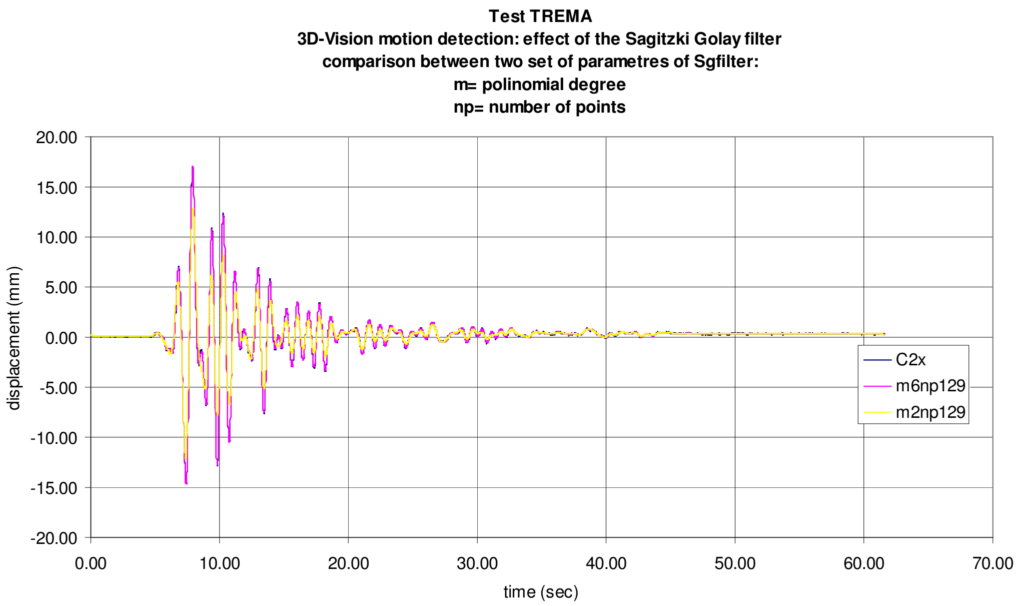

Figure 3a effect of the polynomial degree values in the Savitzky Golay filter of the Displacement time histories detected by the 3D-Vision motion detection system.

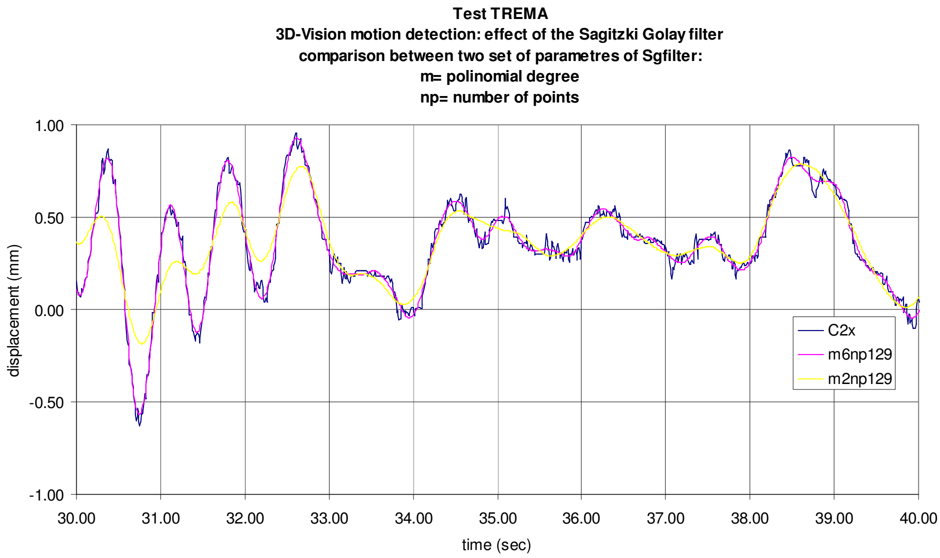

Figure 3b Zoom window of 10 seconds in the interval 30-40 sec

In the following sequence of collapse is evident the capability of the new system to detect the movement of the single points and the collapse mechanisms activated during the seismic experiment.

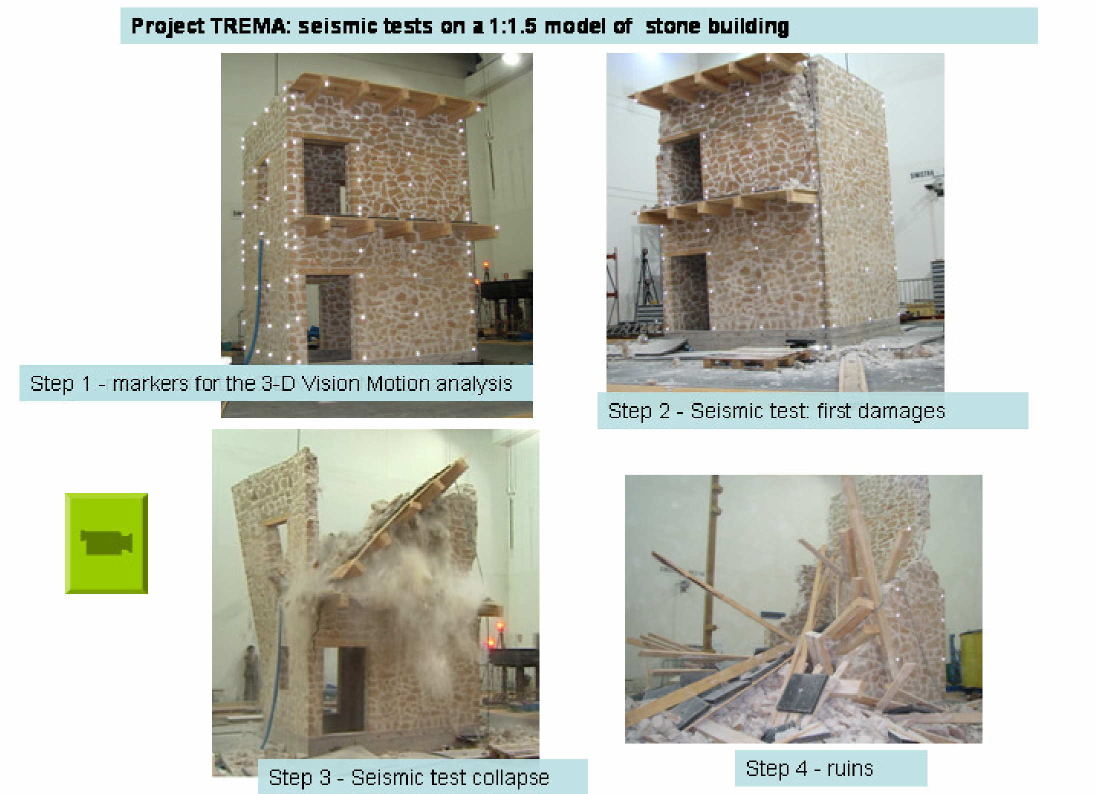

Figure 4 Sequence of collapse of the building during the seismic test

The possibility to synchronize visible and infrared cameras allow the remote participation and control of the shaking table tests in a networking configuration of distribuited experiments. In the following figure is showed the conceptual structure of this networking configuration. This test facility is nested within the ENEA Grid of computational and experimental facilities: the Tokomak particle accelerator at the ENEA Frascati Research center, the ABI Prism 3700 DNA sequence system at the ENEA Trisaia Research Center, the 300 KeV Electron microscope at the ENEA Brindisi research center and the (future) CTM test facility for simultaneous mechanical-Climatic experiments at the ENEA Portici Research center.

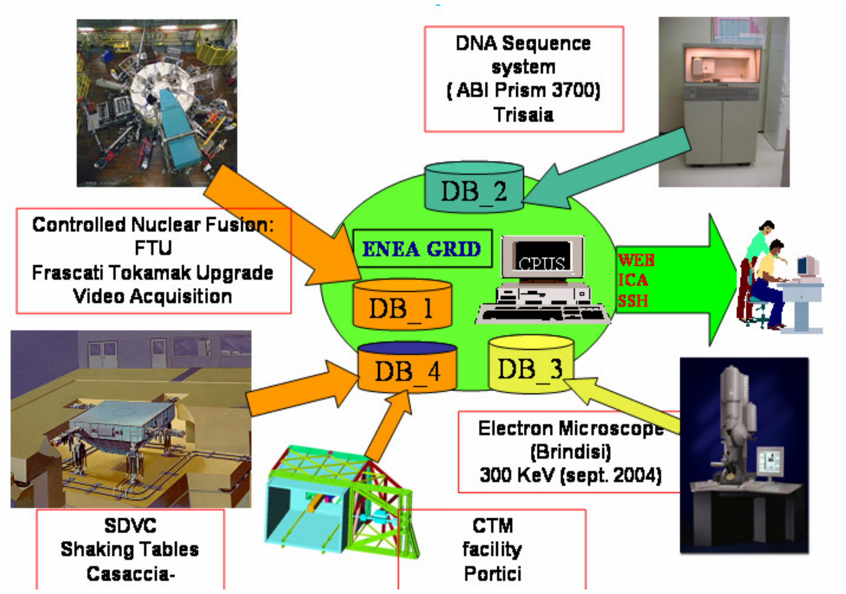

Figure 5 ENEA Grid of remote controlled test facility

The conceptual structure of the remote shaking table operations is shown in fig. 6. At this stage the remote operator share data and image during the experiments and communicate with the local user, the only operator abilitated to drive the test.

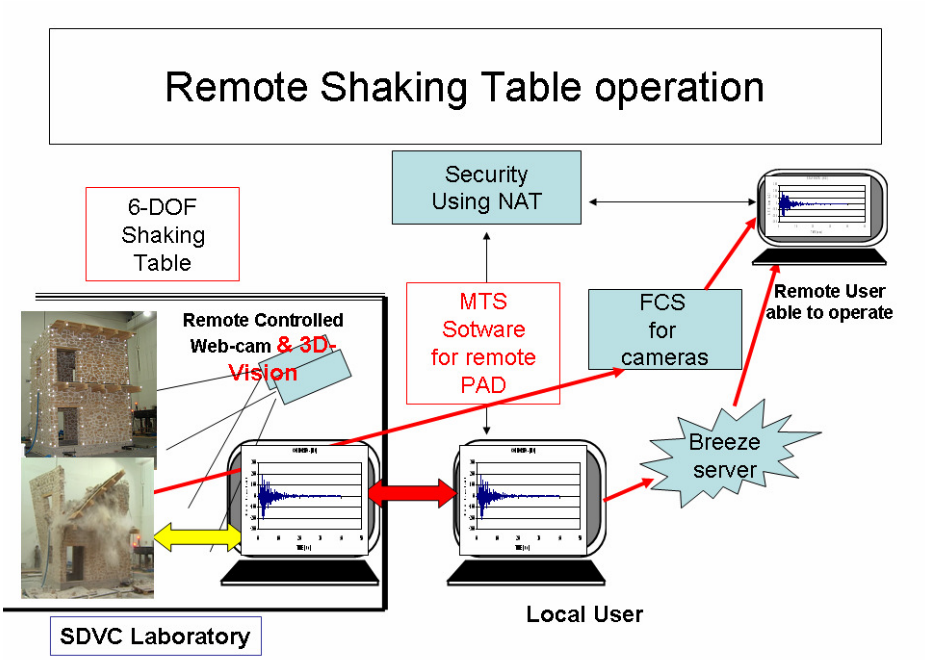

Figure 6 remote shaking table operations

3. OPTICAL FIBER SENSORS

The monitoring system based on FBG (Fiber Bragg grating) sensors is very useful in detection strain fields and structural failure. The system has been tested during the shaking table experiments at the ENEA SDVC laboratory, the results show the feasibility of the monitoring system. The choice of Optical Fiber sensors of FBG type is motivated by their specific properties, allowing long time monitoring of quasi static and dynamic deformations, with high resolution, accuracy and stability. The cabling is simple and allows a large number of sensors on a single optic fiber in WDM regime: this is of extreme interest for large infrastructures like bridges and commercial buildings and for historical architectural structures where the cabling impact should be as less invasive as possible. The Shaking table tests have been performed on a 1/3 scaled concrete model reinforced using the CAM system (a pre stressed wrapping chain by stainless steel closed wires, see the figs. 7 and 8). Three FBG sensors have been applied (FBG1, FBG2 and FBG3) working at the following wavelength:

Table 3.1 Wavelength and sensitivity of the FBG sensors

FBG sensor	FBG1	FBG2	FBG3
Wavelength (nm)	1545 nm	1538 nm	1546 nm
Sensitivity	1.2 E-3 Strain/pm	1.2 E-3 Strain/pm	1.2 E-3 Strain/pm

Their position is shown in the fig. 6a, the sensors FBG1 and FBG3 are positioned along the up-down direction on the column, the sensor FBG2 is positioned on the "Cam stainless wire". The fig.7 show the test mockup on the shaking table designed for non seismic zone and reinforced using the CAM system.

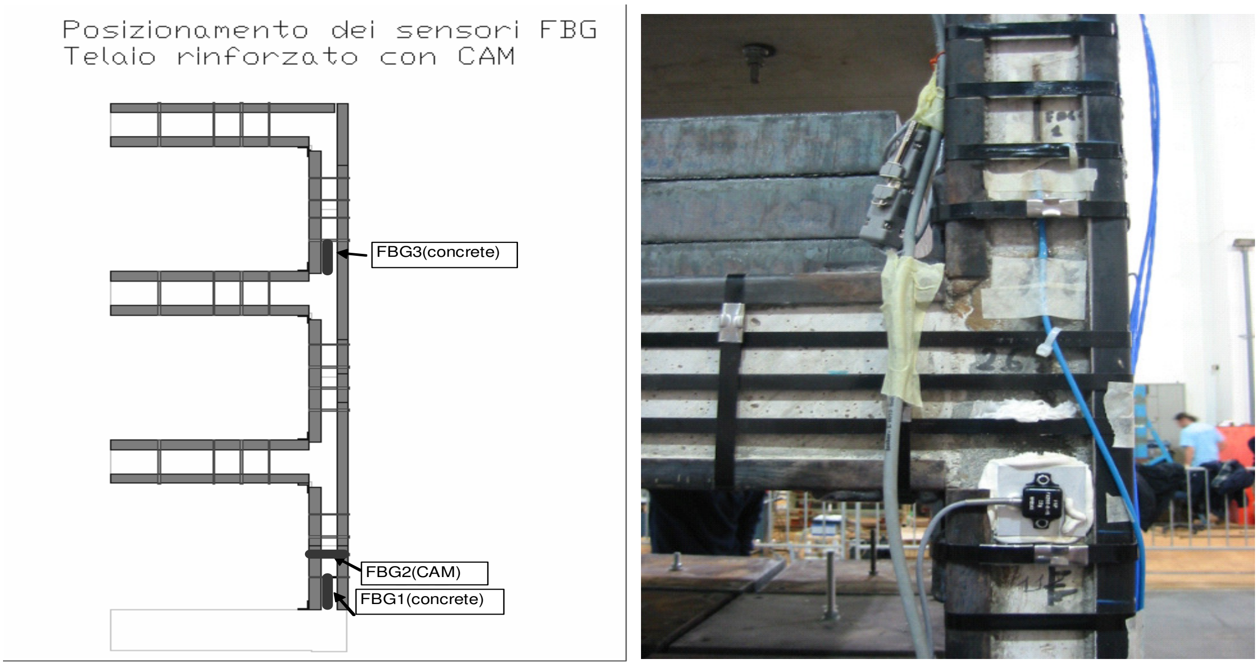

Figure 7 Position of the FBG sensors on the Concrete Frame structure and on the CAM.

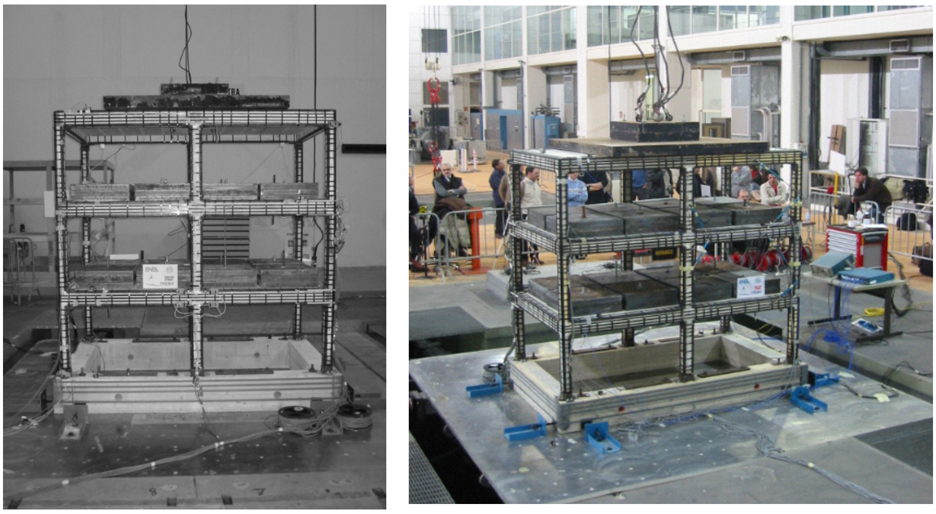

Figure 8 The RC frame during the Shaking Table tests

The results in fig. 9 show that the FBG sensors can detect the dynamic of the structure within the range of the mechanical vibrations. A sequence of 3 consecutive time history has been applied repeating, at each test, three time the NS and EW components registered at Colfiorito during the Umbria Marche earthquake in Italy. The fig. 9 show the NS and EW accelerograms and response spectra.

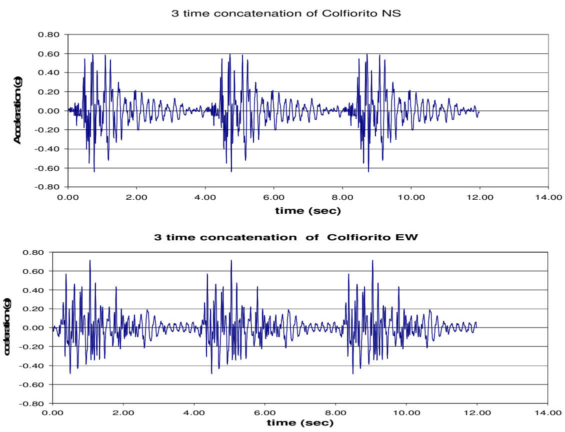

Fig. 9. Normalized accelerograms of the Colfiorito NS and EW components already scaled in time for the shaking table tests.

The graphics in fig.10 show the time and frequency domain data, at two different Normalized Peak Acceleration (the Peak Ground Acceleration of the original earthquake at the same level of energy), monitored by the FBG sensors.

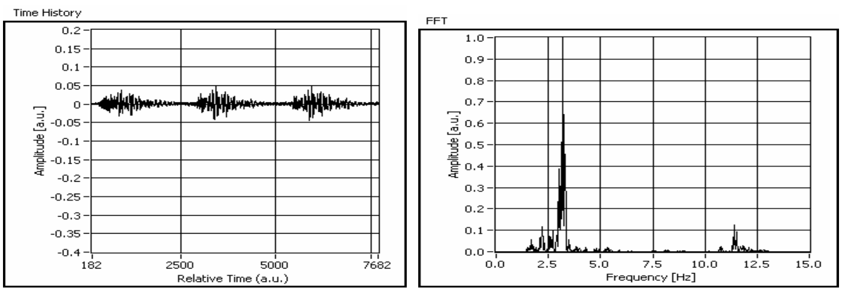

Fig. 10a. Sensor FBG1: time and frequency domain data during the test at NPA=0.10g

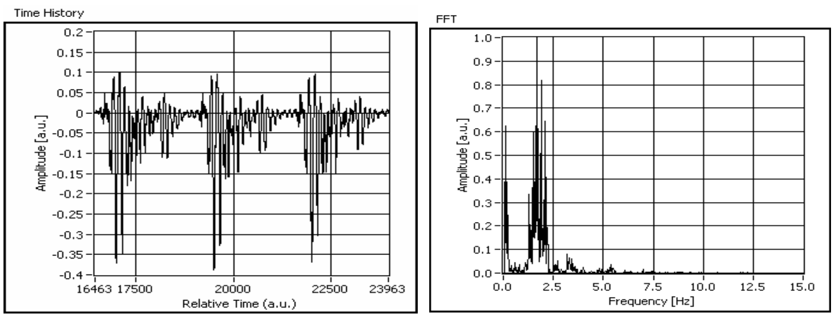

Fig. 10b. Sensor FBG1: time and frequency domain data during the test at NPA=0.70g

The frequency shift from 3.2 Hz at NPA=0.1g to 1.9 Hz at NPA=0.7g corresponds to large structural damages

4. CONCLUSIONS

The results show good results of the 3D-Vision Optical displacement measurement and the FBG strain measurements during Laboratory tests on RC and masonry buildings. The results are useful within the displacement based approach in seismic engineering.

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