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STRUCTRUAL MONITORING AND ASSESSMENT OF THE SCHOOL OF ENGINEERING MAIN BUIKDING AT UNIVERSITY OF NAPLES FEDERICO II

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Abstract

The aim of structural health monitoring for civil structures is not only detection of sudden or progressive damages but also evaluation of their performance under operational conditions or under some particular environmental issues such as earthquakes. Since a large part of the Italian country is exposed to medium/high seismic risk, effective measures have to be taken in order to protect constructions at risk and to mitigate losses due to seismic events.

This circumstance points out the need to monitor performance of civil structures over their operational lives. In recent years, many research projects have been issued to give answers to practical needs and to improve the safety of existing constructions. Attention has been then paid both to technological issues and to theoretical aspects related to the development of efficient and automated procedures to process data.

The present paper deals with Structural Health Monitoring technologies adopted to analyze the structural response of the School of Engineering Main Building at the University of Naples Federico II.

In particular, after a brief description of solutions and systems installed on the structure, some results of the dynamic identification are reported. Finally, some aspects related to the structural assessment of the building in view of its numerical modeling are discussed.

INTRODUCTION

Europe is characterized by a large number of urbanized areas, where a high percentage of constructions is thirty or more years old. As a consequence, many of the existing structures can be classified as functionally obsolete due to age and to structural deficiencies, and assessment and rehabilitation are becoming critical issues in urban management and planning. Serious damages and structural collapses, occurred in Italy in the late 1990s, pointed out the need to estimate and enhance structural safety of existing structures also towards ‘environmental’ issues, such as earthquakes, and to develop effective measures for the protection of constructions at risk and for mitigation of losses due to seismic events. This objective can be reached by increasing the knowledge of the structural behaviour of existing constructions in order to provide guidelines for the definition of safety measures able to protect structures and achieve, at the same time, a decrease of the probability of structural damages. This circumstance points out the relevance of monitoring the performance of civil structures over their operational lives.

The present paper deals with Structural Health Monitoring technologies adopted to analyse the structural response of the School of Engineering Main Building at the University of Naples Federico II. It contains a description of solutions and systems installed on the structure. They are aimed at assessing the structural response of the building, but also at performing real-time evaluations of the level of safety of the building in the early earthquake aftershock. In this sense, the system should help to produce earthquake scenarios after seismic events and to support the decision making processes. Some aspects related to the structural assessment of the building in view of its numerical modelling are also briefly reported.

SHM SYSTEM OF THE SCHOOL OF ENGINEERING TOWER IN NAPLES

The School of Engineering Tower in Naples (Fig. 1) is a tall building of thirteen stories, two of which are placed underground. The building was designed by L. Cosenza, structural design was by Adriano Galli [1].

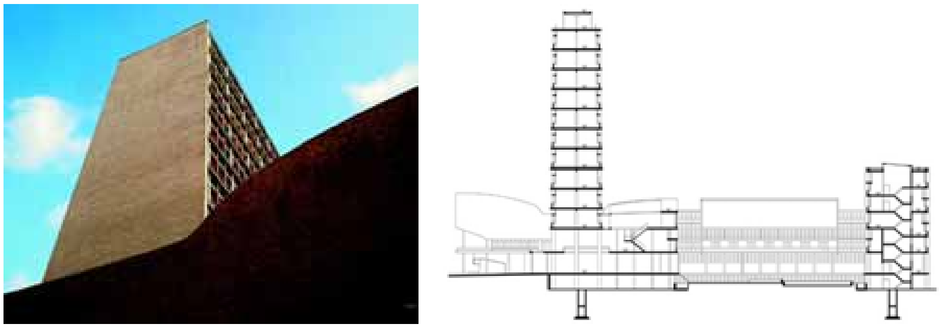

Figure 1. The tower of the School of Engineering

It is characterised by a reinforced concrete structure designed and built during the early 1960s to bear gravity loads. During the 1980's the framed r.c. structure was strengthened to bear seismic loads, according to current seismic codes, after that Irpinia Earthquake (1980) struck Naples. The building is located in a much urbanised area, in the vicinity of a number of surface and underground railways, and near the S. Paolo stadium. In addition, it is placed in a medium to high seismic risk zone according to recent seismic design guidelines [2], is near the active volcanic area of Campi Flegrei, and the high seismic risk area of Irpinia.

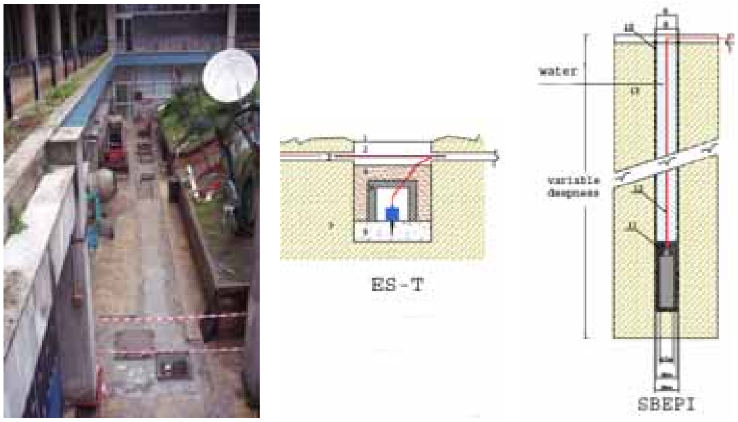

Figure 2. Layout of geotechnical sensors

The tower has been equipped with a monitoring system aimed at the identification of the modal parameters in operational conditions [3]. Another relevant target is the investigation of soil conditions and of soil-structure interaction. Figure 2 schematically reports the layout adopted for geotechnical sensors. The monitoring system is connected to the regional seismic network issued in the framework of the AMRA project (www.amracenter.com). It is worth noting that the Irpinia Seismic Network (ISNet) was designed in 2002 as an advanced research seismic network [4]. It is managed by the RISSC research group (a joint research group between the Physics Department of the Federico II University of Naples and the INGV-Osservatorio Vesuviano, Naples). ISNet is a highly dynamic, high density seismographic network and has a complete new communication and site infrastructure. Its fully digital and fast acquisition communication system fits very well with requirements of early-warning systems. Data coming from the network are stored in the Database of the SHM system and will increase the knowledge about propagation of seismic waves and site effects.

In summary, a monitoring system combining structural, geotechnical and seismological model has been designed. It is an open system, being expandable through various data acquisition and transmission systems. It consists of a variety of sensors (anemometers, accelerometers, displacement sensors) to monitor the environment, the soil, and the structural response to loads. The architecture of the monitoring system has been designed so that it is able to transmit data also in critical conditions, such as during an earthquake: in fact, the data collected during and immediately after a seismic event are essential to produce scenarios and support the rescue operations; moreover, those data can help to have a deeper knowledge of the structural behaviour in the case of extreme load conditions, such as earthquakes. Groups of three sensors are linked to intelligent electronic systems, called T-Nodes, that are able to perform transducers conditioning, checks of sensor efficiency, and A/D signals conversion. The T-Nodes are wired to a local slave: it is a unit for collecting, synchronizing, and transmitting data to a central unit by redundant transmission vectors. The central unit is the local master (Fig. 3), which is equipped with a module for supply and management of the sensors. The local master has to store, validate and process data, and transmit the results of analyses to a control panel which shows the location and activity of the sensors on the structures and, on demand, the acceleration waveforms of selected channels and the results of the identification process. The control panel can be accessed through an internet connection.

Figure 3. The local master and the K2 Digital Recorders

The data incoming from the sensors are stored into a MySQL database organized in columns reporting time, GPS status, values of the measurements; it also contains information on settings of the sensors (i.e. sensitivity, full scale) and the unit of measure for each channel. These data can also be downloaded manually through “MySQL Query Browser” for specific purposes; selected users can access the data and select them through appropriate “queries”. Data of interest can be exported in different formats depending on the specific use. Sensors are installed at the third, the seventh and the roof (Fig. 4). Accelerometers are placed along the north-south direction and the east-west direction in two opposite corners of the building and in two opposite corners nearby the stairs. The monitoring system is equipped by three GPS antennas to get the absolute time and synchronize the measures of the various sensors in the database. The structure has been also equipped by an independent system, a Kinemetrics Altus Digital Recorder (Fig. 3) connected to EpiSensors ES-U2, to obtain a redundancy of the monitoring system and compare performances. Also the data coming from the Kinemetrics recorder are stored into the database, using an appropriate system able to transfer the data from K2 to the database through LAN.

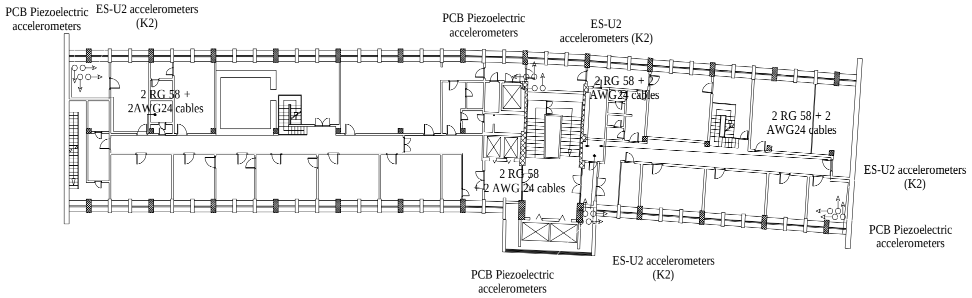

Figure 4. Roof sensors

In regards to the acceleration sensors mounted on the structure, the School of Engineering Tower has been instrumented at the upper levels with two type of accelerometers: uniaxial force-balance accelerometers by Kinemetrics inc. (model FBA ES-U2; 2.5 V/g of sensitivity; ±1 g and ±0.5 g of full scale range) linked to the Kinemetrics K2 Digital Recorder, uniaxial piezoelectric accelerometers by PCB Piezotronics inc. (models 393B04 and 393A03) linked to the SHM system. Geotechnical parameters are monitored through Kinemetrics EpiSensor ES-T mounted at the base of the building, and through Kinemetrics Shallow Borehole EpiSensor SBEPI which are underground and are managed in collaboration with a geotechnical research group from University of Calabria in Cosenza, coordinated by Prof. Francesco Silvestri.

With the aim of the identification of the dynamic parameters of the structure under operational conditions, a software in LabView environment for data processing has been developed and tested [5]. Moreover, a specific module for data pre-processing (mean and trend removal, data classification and validation, identification of spurious harmonics through Short Time Fourier Transform of the responses shown in a contour plot, filtering) has been implemented. The software has been validated using numerically simulated data obtained from numerical models before using field records [6]. A software solution for continuous automated extraction of the dynamic characteristics of the structure has also been implemented and is currently under test [7].

THE MODAL PARAMETERS IDENTIFICATION TECHNIQUE

The evaluation of the modal parameters of the structure has been performed in output-only condition through the use of the Frequency Domain Decomposition technique [8]. It is an extension of the Basic Frequency Domain technique, often called the Peak-picking technique [9]. Performing the singular value decomposition of the output PSD matrix known at discrete frequencies $\omega=\omega_i$ one obtains:

$$\hat{G}_{yy}\left(j\omega_i\right) = U_i S_i U_i^H \tag{1}$$

where the matrix U_i is a unitary matrix holding the singular vector u_{ij} and S_i is a diagonal matrix holding the scalar singular values s_{ij}; the superscript ^{H} denotes complex conjugate and transpose. Near a peak corresponding to the kth mode in the spectrum, only the kth mode is dominant, and the PSD matrix approximates to a rank one matrix as:

$$\hat{G}_{yy}\left(j\omega_i\right) = s_i u_{i1} u_{i1}^H \qquad \omega_i \to \omega_k \tag{2}$$

The first singular vector at the k-th resonance is an estimate of the k-th mode shape [10]. In case of repeated modes, the PSD matrix rank is equal to the number of multiplicity of the modes. In summary, modal frequencies can be located by the peaks of the singular values plots, while the corresponding first singular vectors give the mode shapes. Finally, to estimate damping ratios, the singular values near the peak with corresponding singular vector having MAC higher than a MAC rejection level are transferred back to time domain through inverse FFT, obtaining an approximated correlation function of the equivalent SDOF system from which damping ratio can be calculated by the logarithmic decrement technique.

THE MODAL IDENTIFICATION RESULTS

Data recorded on the structure are processed to extract dynamic parameters of the structures, i.e. modal frequencies and shapes. To this end, a preliminary classification and validation of the data is performed, in order to assess stationarity, presence of spurious harmonic components, and the statistical distribution. In particular, data standardization is carried out to check the basic assumption of normally distributed experimental data. In addition, clipping, drop-out are also checked and removal of means and trends are performed. Figure 5 confirms that environmental vibrations of the building can give good records, as reported data fit very well the normal distribution and exhibit a Kurtosis index of about 3. Analyses are carried out using an Hanning window to reduce leakage, and with a 66% overlap.

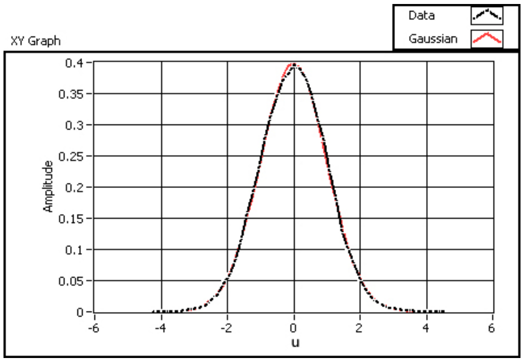

Figure 5. Data distribution

Table 1. Results of identification

Mode number	Type	Frequency [Hz]	Damping Ratio [%]
1	Prev. translational (long side)	0.93	≈ 3
2	Prev. translational (short side)	0.99	≈ 3
3	Prev. torsional	1.30	≈ 2

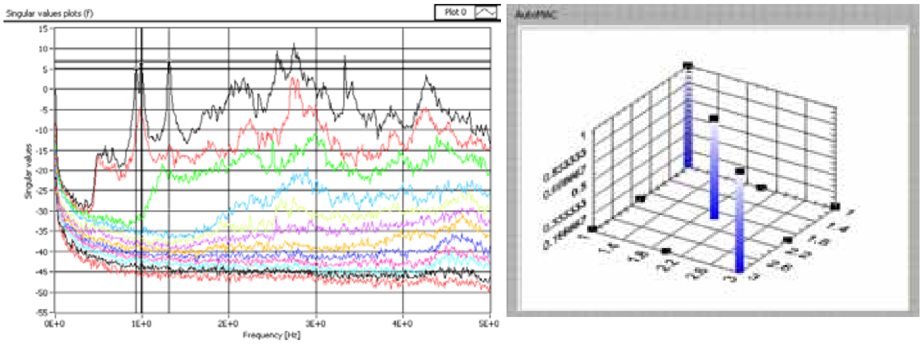

Figure 6. Singular Values plots and AutoMAC matrix

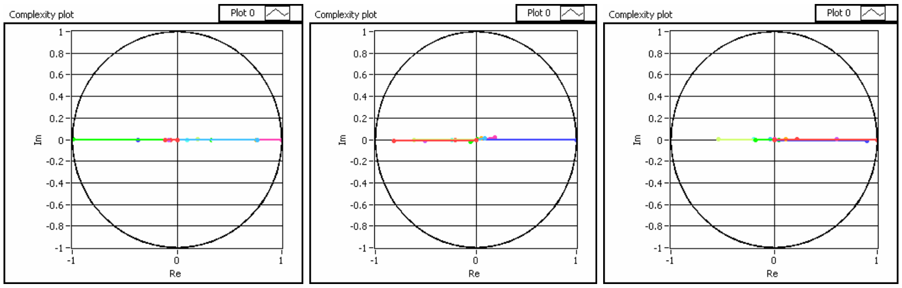

Figure 7. Complexity plots for the three identified modes (from left to right)

In Figure 6 (left) one of the Singular Values plots obtained is reported, and the peaks relative to the first three modes are indicated. The results of identification process in terms of natural frequencies, damping ratios and mode shapes are reported in Table 1.

In Figure 6 (right) the AutoMAC matrix histogram is also reported. It has been used to have a first validation of the experimental results, witnessed by the values of 1 along the main diagonal and close to 0 in the rest of the matrix. Another check of the obtained mode shapes has been carried out by the Complexity Plots (Figure 7): these plots are useful in order to verify if mode shapes are normal or not. As shown in the figures, all identified modes are normal.

STRUCTURAL ASSESSMENT AND MODELING

Assessment of the building structure has been undertaken, evaluating a number of sources of information, in compliance with relevant National [2] and International [11] Codes concerning seismic evaluation of existing constructions. Available design drawings and reports have been carefully analysed in order to identify primary design data, i.e. gravity and accidental loads (i.e. wind loads). Figure 8 shows an example of an available original design documentation that refers to the geometry of columns located in the area of the tower. A reduced number of field checks have been currently carried out, due to functional problems.

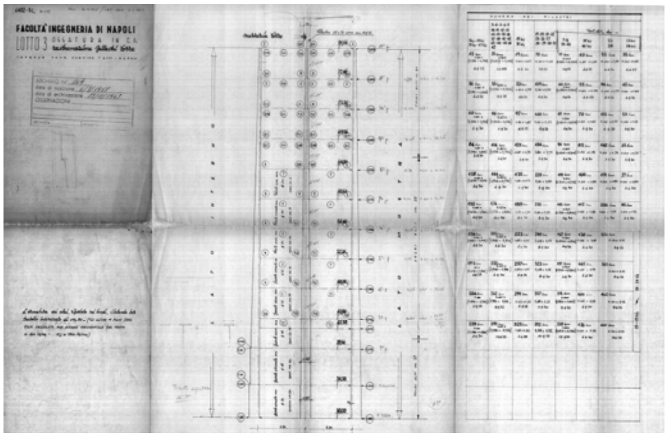

Figure 8. Design cross section of the building and column geometry.

Figure 9. Field verification of design data.

A number of finite element models of the structure has been set up on the base of available data in order to perform a numerical evaluation of the relevant dynamic parameters of the building. In particular, the main objective of such phase of the research is to get information on the role of structural and non-structural elements on the overall performances of the structure. Finite element models are based on the assumption of rigid floor and can be classified into two main classes: in the first class, the dynamic response of the building is evaluated on the base of structural elements only; in the second class, both structural and non-structural elements (such as curtain walls) are considered. Within each class, some parameters, such as the Young's moduli of the different materials and the amount of live loads, have been changed according to ranges compliant with provisions of National and International codes concerning Service Limit States (SLS). Figure 10 reports a 3D view of the geometry of the model.

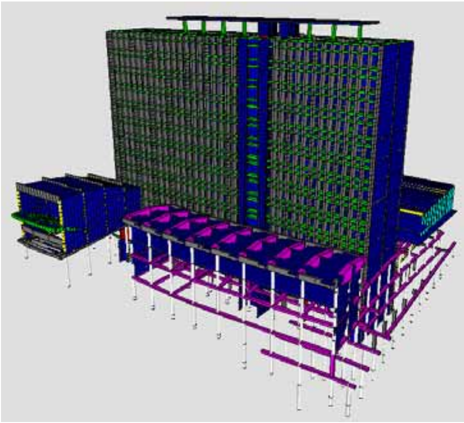

Figure 10. Finite element model of the building.

Preliminary results show that, considering only the structural elements, the effective stiffness of the structure is under-estimated. Thus, the influence of partitions and non-structural components on the dynamic behaviour of the structure cannot be neglected. An optimization process is under development: however, it is worth noting that, considering the first three modes, scatter between bare r.c. frames and experimental data is about 40% on average, while, as non-structural walls are taken into account, the scatter is about 10%. These last results better agree with experimental data, even if some improvements of the structural model have to be made in order to increase MAC values that are not fully reliable at the present stage.

CONCLUSIONS

In the present paper, the Structural Health Monitoring technologies adopted to analyse the structural response of the School of Engineering Main Building at the University of Naples Federico II have been presented: in particular, a description of solutions and systems installed on the structure has been reported, pointing out the main features and targets of the systems. In particular, the connection of the system to the regional seismic network assures real-time information about the characteristics of the incoming seismic events in a high seismic risk area such as the Neapolitan area. Such information can lead to the identification of critical events. The use of redundant vectors (DSL connection, traditional or cellular phones, satellite) for data transmission assures the effectiveness of the system even if an earthquake occurs. Experimental identification of relevant dynamic parameters has been carried out using OMA based procedures. Structural assessment and numerical modelling of the building confirm experimental estimations, but require further developments primarily as extension of field checks is considered.

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