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Repair and Health Monitoring for Historical Structures

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Abstract Historical structures, like to masonry towers and another structures are among the structures subjected to the higher risk, due to their age, elevation and low base area on height ratio. In this paper introduce a technique of monitoring the structural integrity of historical buildings by a noncontact and non-destructive analysis is presented and discussed. The damage and destroy of a structure and building, in terms of cracks and overall structural degradation, is detected throughout the measurement of its dynamic characteristics by various ways, for example by a laser Doppler vibrometer(LDV). These techniques can show the frequency spectrum of the structure with high accuracy and reliability and reaction of structure against this technique. Also we will introduce that timber components have no influence on the system behaviour, which is mainly determined by the properties of connections and reactions.

Keywords: Characteristics, historical building, repair, structure, vibrometer

Introduction

The knowledge of the health conditions of historical buildings is a great concern for many towns in the world, where is possible to find a large number of ancient structures and other monuments well known all around the world. The problem of the conservation of historical buildings and of the estimation of the residual life before maintenance is studied from some decades. For example review of the studies on various aspects of these theme, is widely illustrated. The monitoring of the structural integrity of historical buildings is needed to preserve the precious cultural inheritance from the past. Churches, Mosques, masonry towers and bell towers are among the structures subjected to the higher risk, due to their age, elevation and low base area on height ratio. Another problem for the stability of ancient buildings is the massive presence of car and heavy vehicles traffic, that causes random vibrations. A building which suffers this kind of degradation is the Steccata church (Italy). In this paper a relatively new non-destructive technique for the monitoring of the structural integrity of buildings is presented. The aim of this technique is the identification of the building's dynamic characteristics. Each body has its own shapes, frequencies of vibration and dumping properties (the modal parameters), that are a function of its mechanical characteristics: a damaged structure shows a frequency autospectrum which differs from that of the integral one. The detection of the dynamic characteristics of a building can then identify the presence of damaged zones, cracks and structural degradation during the time. The methodology of measurement here proposed makes use of a laser Doppler vibrometer (LDV technique), a relatively new non-contact detection technique that provides measures of displacement with great accuracy and reliability. The results of measures are elaborated via computational programs to identify the modal response of the structure and detect the evolution of any damaged zone by calculating mass and stiffness changes in reverse based on changes in mode shapes. The assessment procedure includes i) full-scale ambient vibration testing of the historical building, being ; ii) the modal identification from ambient vibration responses; iii) the finite element modeling and dynamic-based identification of the uncertain structural parameters of the model. The validity of the proposed method is firstly experimentally demonstrated through vibration measurement for a steel plate before and after damage. Also, The investigation is usually carried out where there is the intention of restore, repair or retrofit the building. Nevertheless exist cases when knowledge of the state of damage is in any case important for the safety of the building itself or to understand whether a maintenance intervention is needed. In some cases when the damage can be hidden or difficult to detect, an investigation campaign can save the situation as it happened in the case of the SS.

Importance of On Site Investigation to Detect the State of Damage

The necessity of establishing the building integrity or the load carrying capacity of a masonry building arises for several reasons including: (i) assessment of the safety coefficient of the structure (before or after an earthquake, or following accidental events like hurricanes, fire, etc.), (ii) change of use or extension of the building, (iii) assessment of the effectiveness of repair techniques applied to structures or materials, and (iv) long-term monitoring of material and structural performance. NDE can be helpful in finding hidden characteristics (internal voids and flaws and characteristics of the wall section) which cannot be known otherwise than through destructive tests. Sampling of masonry specimens is a costly operation, which also can lead to misunderstanding when the operation is not carried out in the appropriate way. When an overall knowledge of the wall is needed, ND tests can be useful. The types of tests available at present are mainly based on the detection of the physical properties of the wall. The in-situ mechanical tests available are flat-jack, hardness, penetration and pull out tests. The flat-jack tests give local measurements and are slightly destructive: nevertheless they can give directly the values of mechanical parameters. In the case of ND tests, a correlation between the measured parameters and the mechanical ones is usually difficult, but they can give an overall qualitative response of the masonry. At present the most diffused ND techniques are represented by the sonic (or ultrasonic), radar and thermography tests. Up to now most of the ND procedure can give only qualitative results; therefore the designer is asked to interpret the results and use them at least as comparative values between different parts of the same masonry structure or by using different ND techniques. It must be clear that even if there is a need of consulting experts in the field, it is the designer, or a member of the design team, who must be responsible of the diagnosis and must: (i) set up the in-situ and laboratory survey project, (ii) constantly follow the survey, (iii) understand and verify the results, (iv) make technically acceptable use of the results including their use as input data for structural analyses, (v) choose appropriate models for the structural analysis, (vi) arrive at a diagnosis at the end of the study. These operations can be accomplished with the help of experts in the field. Therefore information is needed for architects and engineers on the availability and reliability of the investigation techniques, which should be used taking into account limits and benefits, always compared to the cost.

Organization of the Study and Civil Importance

The knowledge of the health state of ancient buildings has a big importance for the maintenance and tutelage of historical structures. The work here presented has the double aim: i) to acquire the spectrum and the mode shape of the analyzed buildings and ii) to measure the strain and stress in the inner chains of the vaults of churches, that are directly responsible of the structure stability. Both these aspects, conducted via nondestructive techniques, are of great importance from the point of view of the extendibility to other structures and engineering fields. Each detected frequency spectrum, relative to the portion of one single building, is integrated in a data base which will be the history of that building. The program comprehends a five years test plan for each building; in these five years the evolution of the frequency response of the building will be monitored and elaborated, to obtain the trend of behavior of the structure in a mean period. The detection of anomalous dynamic responses will be the basis of a preventive intervention to consolidate the foundations or to apply bearing structures to the building. The same dynamic investigations are able to state the stress in the chains applied to the concave part (i.e. inside the buildings) of the roof vaults of many churches. The problem of the vaults stability, i.e. of the flattening of the roof with consequent deformation due to the roof weight, is actually spread especially for the churches and another structures with a wide central nave, which is a common architectural solution for the Romanic churches. The determination of the stress state in the support chain, usually made of iron and low-carbon steel, is of interest to estimate the residual strength of the chains themselves. Extreme traction states in these supports are a really dangerous condition, especially if overloads, as seismic waves or particular thermal loads, occur in the life of the structures. The rupture of a support chain can be a catastrophic event for the building. The novelty of the present study is the methodology of investigation and measurement by a non-destructive and non-invasive technique, which demonstrates its indisputable advantages when applied to buildings of high historical, civil and artistic value; the experience obtained from the application of this technique to the prevention of some of the numerous historical buildings of different buildings in Italy, can be easily extended to a wide scenario of ancient and newer structures.

The Complementariety of Non Destructive and Minor Destructructive Testing

When a complex investigation is carried out using different techniques, the highest difficulty is represented not only by the interpretation of the results of the single technique but also by the harmonisation of these results. Some questions arise when the designer or responsible of the building repair and maintenance receives the results of destructive and no destructive tests. When radar and sonic tests are carried out on the same wall or pillar, do the result harmonics, so that he same conclusions for both the tests can be the same? Can sonic and double flat-jack tests be in some way correlate so that only few flat-jack, expensive and more destructive, can be carried out and sonic test allow a more extended at least qualitative interpretation? Can core drilling and boroscopy help in sampling material for laboratory tests and detect the morphology of the wall section? These and other questions are still open and a definite answer has not been given, difficulties are due to the inhomogeneity of the material and complexity of the structures. A tentative of giving some answers was done in Binda.

Introduction of Another Assessment Way: Laser Vibrometry Technologies

Optical metrology techniques are effective tools to measure mechanical quantities, by non contact survey and detailed acquisition in the space, time and frequency domains. Within the structural control, laser vibrometry is a modern technology for measuring vibration velocities. Specifically, laser vibrometer allows at detecting the velocity of a moving point focused by a 2 laser beam. The device measures the frequency shift of the laser beam, scattered back from the vibrating surface, according to the Doppler Effect. Light beam from a laser source is split in two same power beams by a splitter. One of the two, called "measuring beam", is focused on the vibrating surface. The other one, called "reference beam" is housed in the laser head. After being reflected, the measuring beam enters back the laser head. Here it is recombined with the reference beam. Surface displacement varies the optical path difference between the two laser beams. This results into a phase lag varying with vibration velocity *v*. As a consequence, a time varying phase difference corresponds to an instantaneous frequency component that follows *v*. This frequency shift is equal to the Doppler shift (f_D) that according with basic physics depends on *v* and source wavelength (λ): $fDoppler\ \alpha\ 2v/\lambda$.

As a result, it is possible to extract the amplitude of velocity *v*, by demodulating the output signal. Laser vibrometry devices are different, according to the operation modes and the performances. A common classification is related to the measured velocity component: in-plane vibrometer, if it measures the velocity component that is parallel to the laser beam direction;

• Out-of-plane vibrometer, if it measures the velocity component that perpendicular to the laser beam direction;

• 3D vibrometer, if it measures all the three dimensions velocity components.

Another classification concerns the number of measures gathered simultaneously:

• Single point vibrometer allows at measuring the velocity only in one point;

• Differential vibrometer detects the relative velocity of two points;

• Rotational vibrometer provides with data referred to a rotating single point;

• Scanning vibrometer measures velocities for a complex set of points and gives a global mapping of the investigated surface.

Most diffused Laser Vibrometers have a maximum velocity range of 10 m/s, with a frequency upper limit of 200 kHz, a resolution of about 1μm/s and a base accuracy in the order of 1%- 2%. Laser power is less than 1mW, so that no special safety measures are required. Nevertheless working distances of some tens of meters are possible with a spatial resolution of 1mm. All the systems are managed by a computer. Results are stored in digital formats as images, movies and text data files for further analysis. As far as the frequencies are concerned, the power spectral analysis has showed the highest amplitudes at about 30Hz and 87Hz (Fig.1).

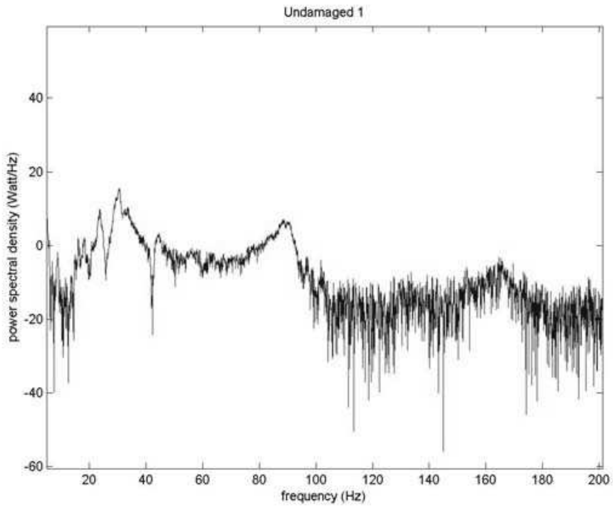

Figure 1: Example of power spectrum from measurement point 1(Damage0)

Conclusions

On site investigation techniques should be slightly or no destructive in order to avoid destruction as much as possible. Nevertheless the calibration of NDT on highly inhomogeneous masonry is very difficult. Sonic tests proved to be successful in all the three mentioned case histories. They were effective when used in simple applications or in a much more refined application. In the first case, it was very easy to understand where the weak point of the pillar was. Flat-jack tests, besides giving the state of stress and the stress-strain behavior help in the explaining given state of damages. Coupling of sonic test and double flat-jack tests can give in the future a correlation between sonic velocities and modulus of elasticity. Also, the present paper illustrates the start of a research activity on structural dynamic. This activity is aimed to the monitoring of the health state of ancient and historical buildings. It is based on the possibility of determining all the significant dynamic characteristics of a building or a monument via non destructive and non invasive sensors (as the Laser Doppler Vibrometry). Although the research is at its early stage, significant data have already been collected. Recently, scientists believe that this kind of work should produce huge impact over the monument conservation branches.

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