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Acoustic techniques for the evaluation of the building materials of monumental structures

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In recent years non-destructive (ND) techniques, based on the analysis of sonic or ultrasonic pulse transmission, have become increasingly important both in the acquisition of objective information on the conservation state of building materials and in the investigation of the effectiveness of repair actions to damaged or deteriorated masonry structures. Altered and weakened zones inside the structures as well as cracks and flaws beneath the surface of the material are characterized by lower acoustic velocity values with respect than values in unaltered and intact materials.

It is a known fact that the characteristics of the acoustic signals are strictly related to the mechanical status of the material. In the present study, to contribute to the knowledge on the mechanical characteristics of the investigated materials, ultrasonic velocity measurements by the direct transmission technique (transmitter and receiver on two opposite faces) were carried out on unaltered samples of different materials prevalently used as building stones on most monumental structures of the historical city center of Cagliari (Italy). Starting from the comparison of these values with the velocity values measured *in situ* on the structural elements made up of the same lithotypes, it is possible to estimate the intensity of the alteration and detect the presence of defects (fissures, fracture, etc.) inside the materials. Data acquisition was done both using the portable ultrasonic non destructive digital indicating tester (PUNDIT) by C.N.S. Electronics LTD, which generates suitable pulses and measures their transit time through the investigated material, and the OYO McSeis 24-channel high resolution engineering seismograph. In the ultrasonic tests, the data acquisition techniques, direct and indirect (Galan et al., 1991; Zezza 1993, 2002; Christaras 1997), selecting

the proper geometries (e.g. transmitter - receiver distance) and frequencies (54 kHz and 24 kHz), were accurately chosen depending on the targets of the investigations.

As part of an experimental research program, different acoustic techniques were used to evaluate the conservation state of the building materials in different architectural contexts and to solve the following problems: (1) evaluation of the general condition of the masonry in monumental buildings, (2) detection of damages inside the building materials, (3) evaluation of the effectiveness of repair actions.

The results of the applications carried out on different monumental structures of the historical city center of Cagliari(Italy) are presented below.

Church of Saints Lorenzo and Pancrazio: the columns inside the church and the external masonry walls of the facade were investigated by the ultrasonic technique with direct and indirect ("step by step" modality) acquisition techniques. The data obtained by direct acquisition techniques (transducers on the opposite surface of the columns) carried out in different directions, allowed to detect the anomalies of the velocity values of the ultrasonic pulse within the material, also providing information on its anisotropy. The indirect arrangement (transducers on the same surface) carried out by the "step by step" modality provided useful information to check the conditions of the different building materials (mortars and masonry) on the superficial parts of the columns and masonry walls. The presence of low velocity zones was related to altered materials and/or mechanical discontinuities.

Church of S. Chiara: the internal masonry walls were analysed by ultrasonic indirect arrangements using the "step by step" modality. Our attention was focused on areas where alteration phenomena, detachments of mortars and stuccoes and presence of mechanical discontinuities, such fissures and cracks, were observed. Particularly, the velocity map realised in the choir in different times both immediately after the restoration works and 5 years later, still showed persistence of low velocity zones coinciding with weakened zones (fissures and cracks restored by filling with synthetic resins) (Grinzato et al., 2004). This is probably a consequence of a scarcely effectiveness of the restoration actions.

Palazzo Regio: The ultrasonic investigations carried out by the "step by step" acquisition scheme were very effective in defining the decay of building materials, and allowed to detect the shallow altered zones in the wall masonry (Fais et al., 2002). The application of ultrasonic refraction technique allowed to reconstruct the thickness of the shallow decay layers and to measure the absolute values of the velocity of the material under the altered layers. The seismic tomography method was applied in a selected critical sector of the masonry wall of the facade. Data processing based on cross-correlation computation (Fais et al., 1999) was carried out to improve the input

velocity model in the tomographic reconstruction. Seismic tomography allowed to define precisely the geometry of an anomalous zone characterised by low mechanical resistance inside the wall. This result was also confirmed by the analyses carried out on the microcores from the critical sector.

In conclusion, in the diagnosis of historical monuments, the integrated application of ND acoustic techniques provides an important and effective contribution to the evaluation of the state of alteration of building materials, allowing to minimise the destructive testing and to apply the more appropriate actions to undertake in the restoration.

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