Nondestructive Testing in Historical Buildings

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The project is co-financed by the European Union through the Hungary-Croatia IPA Cross-border Co-operation Programme

Introduction

Preservation and rehabilitation of historic buildings can be successfully accomplished only if a diagnosis of the state of damage of the building has been formulated.

The knowledge about the building construction should be deep in order to understand:

- the role of all its features and details,
- the characteristics of the materials, and
- characteristics of the structure together with its evolution in time.

Sjedište Požeške biskupije, GF 2003.

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Introduction

The methodologies for the evaluation are based on non-destructive (NDT) and minor destructive (MDT) testing methods that are adapted and optimized to assess selected damages and testing problems

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Introduction

Studies of existing masonry structures are usually conducted to determine:

- as-built and current conditions,
- engineering properties, or for
- quality control purposes.

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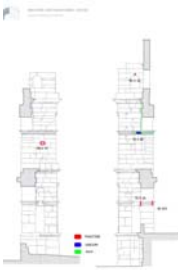
As-built conditions

In the absence of original detail drawings, many evaluations concentrate on simply defining how the structure was initially constructed.

Information on wall thickness, the nature of internal wall construction, and location of brick header courses or stone bond courses can all be obtained through the use of NDT procedures.



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Current condition

All building materials undergo changes in response to applied loads and environmental conditions.

- Damage from seismic action, building movement, freezing cycles, and salt crystallization can be identified with nondestructive testing.

Engineering properties

Engineering analysis requires accurate information on masonry mechanical characteristics as well as the nature of the loads being resisted.

The traditional approach to determine masonry material properties has been to remove samples from a wall for destructive laboratory testing.

In situ test procedures provide a viable alternative and serve to minimize disruption to the area of interest.

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Quality control

Confidence in the use of NDT has reached the point that some techniques are put into regular practice to evaluate recently completed work, whether for new construction or following repair or strengthening procedures.

Nondestructive methods are commonly applied to evaluate pointing mortars, identify grout presence and solidity, and locate embedded reinforcement or ties.

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Introduction

In each case, there are four questions to be answered in order to select the adequate investigation technique and to develop a fitting investigation strategy:

- What information is needed?
- With what accuracy?
- What is the method to fulfill the needs?
- Which decision should be made, depending on the test results?

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Where to use NDT Methods?

Building fabric of high cultural value and protected buildings should not suffer destruction, thus, NDT should be preferred

- NDT is a very good way to do a first survey of the possibilities of planned future interventions or changes to the architecture.
- Some of the NDT techniques provide clues to hidden voids or joints between parts of the building, which originate from different building periods.
- Others are useful to find out characteristic data for structural assessment.

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Where to use NDT Methods?

- NDT can be used to detect hidden elements of the construction as metal anchors, beams or elements consisting of materials with different properties.
- Also, in cases of a very weak structure when even the smallest interventions are risky, as is often the situation after earthquakes or explosions, NDT is a suitable means for investigation.

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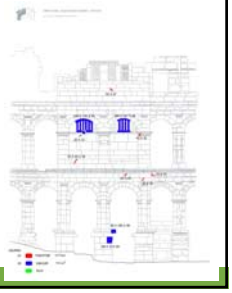
Where to use NDT Methods?

NDT also offers possibilities for quality assurance after the intervention.

- remaining voids, present after the performance of injections, can be satisfactorily shown.

On the other hand, NDT offers possibilities to identify more or less delicate and worthwhile areas of constructions if taking samples cannot be avoided (e.g., to mark out salts inside the building material).



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NDT methods for masonry structures

Useful methods for differentiating between regions of varying quality include:

- Rebound hardness,
- Ultrasonic and sonic stress wave velocity,
- Impact-echo,
- Microwave radar,
- Tomographic imaging, and
- Infrared thermography.

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Rebound Hammer

Surface hardness is measured using a rebound hammer (Schmidt hammer)

Widely used for evaluating concrete, the method is also used for identifying variations in masonry material uniformity.

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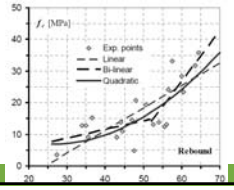
Rebound Hammer

With careful laboratory calibration, it is possible to relate rebound hardness to the elastic properties of the masonry or compressive strength

Rebound hardness measurements are affected by a number of variables, including surface roughness, specimen mass and geometry, vicinity of nearby edges, and hammer orientation.



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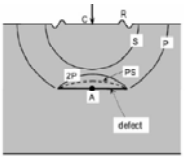
Stress Wave Transmission

Pulse transmission techniques involve measurement of the time needed for an induced stress wave to pass through the material of interest and subsequent calculation of the characteristic wave velocity

Pulse velocity approach is useful for:

- investigating the internal construction of multi-wythe walls,
- locating header courses,
- determining void and spall locations
- identifying masonry damage
- verification of grout solidity and control of grout injection procedures



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Stress Wave Transmission

In a homogeneous material, stress wave velocity is related to the material's dynamic stiffness, Poisson's ratio, and material density.

Laboratory research has shown a relationship between pulse velocity and compressive strength but the method is best used for qualitative purposes

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Stress Wave Transmission

The choice of optimal waveform frequency depends on the investigation's objectives:

- high frequency waves (20 to 100 kHz) - more sensitive to small flaws and voids
- lower frequency waves (usually 1 to 5 kHz) penetrate through thicker cross sections

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Ultrasonic Velocity Testing

An ultrasonic pulser/receiver unit generates a low-energy, high frequency stress wave.

Transducers are coupled to the masonry surface using silicon sheets or gels for maximum energy transmission.

The wave travels through the section where the receiving transducer converts the wave energy back to electrical energy.

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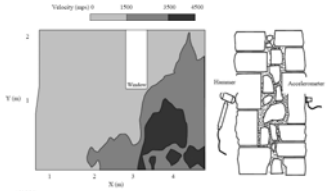
Sonic Velocity Testing

Lower frequency sonic stress waves are generated using an instrumented hammer.

The mass and hardness of the rubber hammer head define the energy and frequency content of the initial wave



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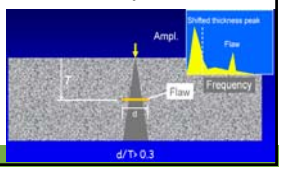
Impact-Echo

The impact-echo approach is a variation of the stress wave transmission method that uses a frequency-based analysis of wave echoes propagating within the masonry

A transient stress wave is generated at the face of the wall typically using a hammer hit or other mechanical impact.

Wave energy is reflected at impedance variations, or discontinuities, within the wall,

- an air void, the boundary between a masonry unit and adjacent grout, or at a crack.



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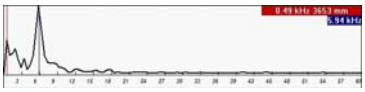
Impact-Echo

The resulting waveform is then analyzed in the frequency domain to identify dominant frequencies.

Knowing the characteristic compression wave velocity, the depth of discontinuities can be identified as a function of frequency.

Impact-echo approaches are attractive because access is required to only one wall face.



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Ground penetrating radar GPR

The GPR system uses reflections of wave energy to identify internal anomalies.

It is based on the electromagnetic wave transmitter and receiver (the antenna)

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Ground penetrating radar GPR

It is being used for:

- detecting inclusions, voids and other defects
- locating bond stones and header courses
- determining thickness of retaining walls, characterizing multi-wythe walls
- locating grout in reinforced masonry construction
- Identifying reinforcing bars or embedded structural steel
- determining effectiveness of repair techniques
- qualifying the state of internal damage or deterioration in walls
- measuring moisture content
- locating regions with high salt content

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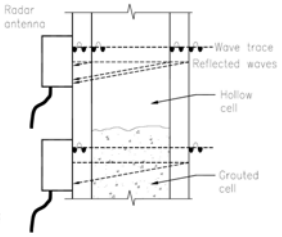
Ground penetrating radar GPR

GPR resolution and penetration depth is dependent on the wave frequency, which typically is in the range of 200 MHz to 1.5 GHz for masonry investigations.



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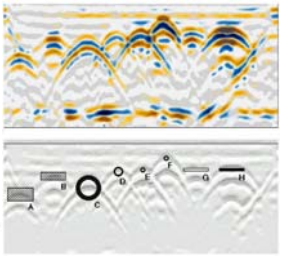
Ground penetrating radar GPR

At present time, commercial or specifically developed radar system are applied to historical masonry structures by mostly executing 2D profiles in impulse-echo configuration.

Data is analyzed in the time domain, rather than converting to the frequency domain.

Care must be taken when interpreting radar traces due to the many reflective interfaces present in masonry construction



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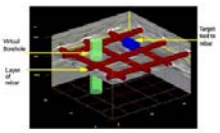
Metal Location

Equipment for locating metals embedded in masonry walls are based on either magnetic or eddy-current principles.

Is used for locating wall ties, reinforcement, or structural steel members within masonry sections.



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Infrared Thermography

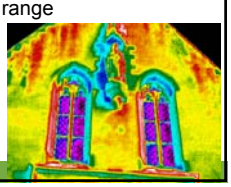
Infrared thermographic imaging provides a visible representation of infrared energy radiated from an object.

In a transient state of heat flux, differences in surface temperature will exist in the vicinity of:

- materials with different densities, heat capacities, and/or thermal conductivities;

These variations in surface temperature are measured using special cameras sensitive in the infrared range

Crkva Sv. Marka



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Infrared Thermography

Application to evaluating features of masonry building envelopes

- Subsurface anomalies: voids, near-surface cracks, incipient spalls
- Variations in wall construction
- Missing or displaced wall insulation
- Moisture rise by capillary action
- Air leakage and variations in moisture content
- Features hidden by surface plaster or frescoes (blocked openings or previous repairs)
- The presence of grouted cells in reinforced masonry construction
- Thermal bridging of mortar obstructions in wall drainage cavities

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Infrared Thermography

Infrared imaging may be conducted using either an active or passive approach.

Active thermography relies on homogeneous forced heating of the wall using an external heat source

- Imaging during heating or cooling (after removal of the heat source) provides information on near-surface anomalies

Holstein, Taunus

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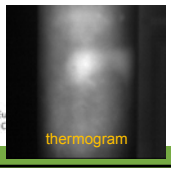
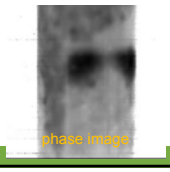
Infrared Thermography

Use of infrared images relies on interpretation by the user to determine the meaning of temperature anomalies.

- Operator experience is essential as well as understanding of the physics behind heat transfer processes and the performance of masonry wall assemblies
- Under different heating and cooling conditions, defects may show as either warmer or cooler regions.

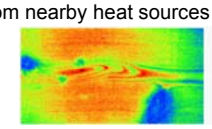
Altes Museum, Berlin

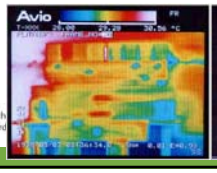




Infrared Thermography

Temperature variations may also arise due to differences in material moisture content, surface texture, material emissivity, or reflections from nearby heat sources

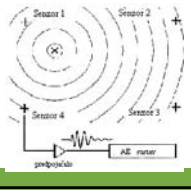




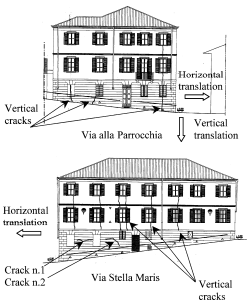
Acoustic emission

In particular, it is used to monitor the conditions of components subject to tension and distortion states

The onset of damage in a structure is in fact preceded, and accompanied, by an emission of elastic waves that spread in the material and can be received and recorded by sensors applied to the external surface.



Casa Capello in Rivoli (Turin)



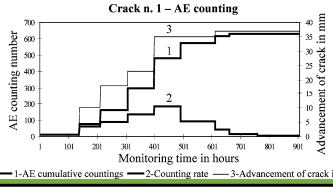
Cracks n. 1 and n. 2 in the inner wall; PZT transducers placed at the tip of the cracks and AE monitoring equipment

Acoustic emission

Having identified the location of cracks or other lesions in a structure, it is possible to evaluate the evolution of the damage, which may come gradually to a halt or spread at a faster rate.

It is also possible to pinpoint the position of damages (not known beforehand), by means of a plurality of sensors and through triangulation.

Cumulative counting *of AE events measured during the monitoring* is juxtaposed to the curve illustrating crack growth in mm



Flatjack Methods

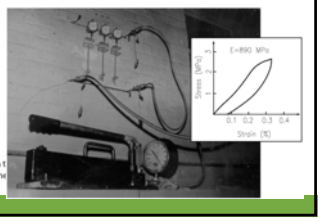
Flatjack test methods provide reliable means for in-place determination of existing masonry stress and masonry behavior subjected to uniaxial compression

When pressurized, the flatjack exerts stress on the surrounding masonry and by measuring surface deformations, information on the existing state of stress, the stiffness and strength of masonry can be obtained

Flatjack Methods

Knowledge of the state of stress in masonry is important for determining applied loads, calibrating analytical models or detection of stress gradients across wall sections.

The method may also be used for identifying potentially hazardous overloading situations such as the buildup of unexpected stress in masonry veneers



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Diagnosis methodologies on timber structures

In recent years, there has been a considerable increase in application of NDT techniques to timber using instrumental methods.

As far as evaluation of the resistance of in-situ timber beams is concerned, most of these techniques are still at the experimental stage and may be adopted to integrate visual inspection bet never, in any case, to replace visual inspection.

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Diagnosis methodologies on timber structures

The speed of propagation ***v*** of ultrasonic pulse is calculated according to time and the distance between the transducers.

From this value and from the volume mass of the wood, it is possible to obtain the dynamic modulus of elasticity E_{din}

Ultrasound has demonstrated effective on certain wood species both as a predictive instrument for evaluation of mechanical characteristics and for identification of zones attact by fungi.

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Hardness of the wood

Hardness of the wood is closely linked to the volume mass of a material.

Subsequent application of suitable corrective coefficients, according to wood species and the defects of a single beam allows for a good estimation of "default-free" wood properties.

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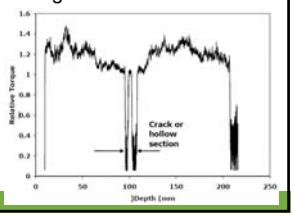
Resistograph

Resistograph assesses the density of the wood by measuring its resistance to penetration

Such instrument is able to assess the internal discontinuities in the wood, to provide indications on resistant section and to measure the thickness of the growth rings.



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Core-Drilling Technique on Wood

NDT tests can give a qualitative information about the overall member strength but without any other information about destructive parameters, the quantification of test results is difficult and unreliable

Use of core drilling includes:

- density, moisture contents, and age determination
- used to establish compressive strength and modulus of elasticity of wood in compression along fibers
- Cores of about 12-mm in diameter have been used to test shear strength of a glue line in the laminated timber

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Conclusions

The careful preparation of the investigation together with a precise description of the problem is a basic condition of every successful NDT and MDT application.

It is necessary to take into account all available information and documentations about the object of investigation

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Conclusions

In spite of the recent advances in NDT technology, it is important to understand that, at the present time, there is no single technique that is appropriate for all situations.

Careful application of complementary techniques often provides the most useful information

Inevitably, interpretation of NDT results involves some degree of assumption about the structure, and the use of calibration measurements is an essential feature of most non-destructive surveys.

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Thank You for Your kind attention!

Bojan Milovanović

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