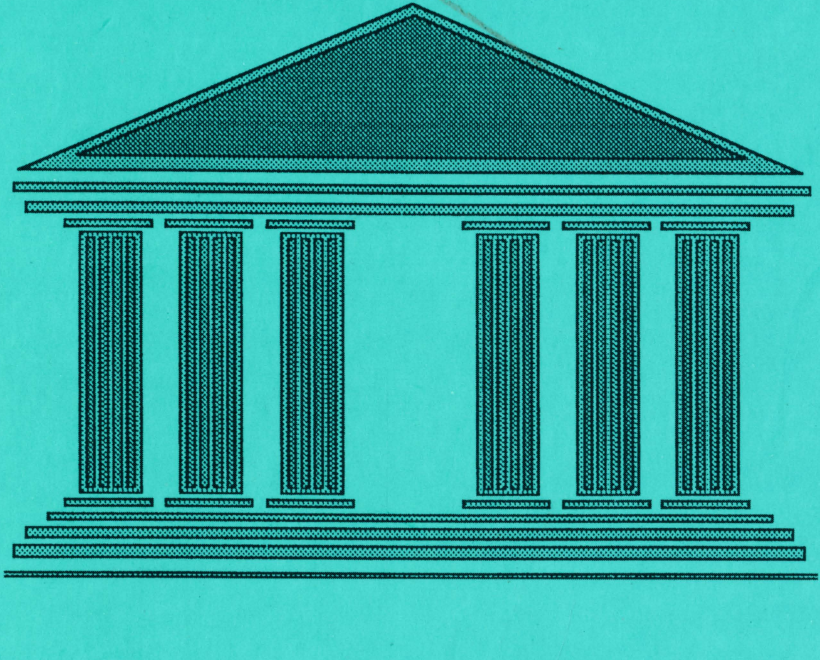
NON-DESTRUCTIVE TESTING ON HISTORICAL MONUMENTS



S. Heruc

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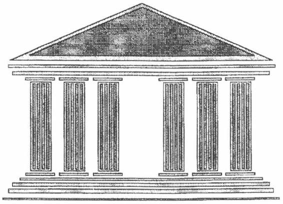

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Svebor Heruc

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Table of Contents

1 Foreword

When dealing with the conservation of historical buildings an in depth inquiry on the structure as well, the detection of the damaged areas are needed before deciding type and extension of the repair. During and after the restoration, the effectiveness of the intervention must also be verified. Among all the available methods, the non-destructive tests are of great importance and provide accurate quantitative data for research, restoration and reference purpose.

It must be pointed out that most of the non-destructive tests applied to historical buildings, have been developed in other scientific areas and technologies, therefore many problems still have to be solved before implementation of those methods to the specific needs of the conservation.

In this book are the non-destructive testing methods described, which are applyed by the author on many buildings, mainly historical monuments. Special attention is made to the monumental monitoring system (MON) which is developed by the author on the Faculty of Architecture, division restoration technology of the Delft University of Technology in The Netherlands.

2 Introduction

Historic monuments are more than just old buildings or architectural importance. They are a symbol of our cultural indentity and in continuity a part of our heritage, and as such it is generally accepted that they should be maintaned for so long as possible and without materially altering the fabric of special architectural features. Therefore the maintenance and care of these buildings must be long term planned and viewed over time span running into hundreds of years.

Monuments require quality control within real time and on large number of measured places, and these requirements may be satisfied only by the controlling methods without destruction. The development of electronics and other scientific disciplines lead in the last decade to the appearance and improvement of a number of methods enabling direct testing of materials inbuilt in structures.

The inspections should diagnose the causes and propose an effective cure that involves the minimum of intervantion. Such inspections have three main aims: the first is to spot defects which require immediate attention; the second is to record the condition of elements in order to plan maintenance works or alter existing plans; and the third is to monitor the effectiveness of repair and maintenance work. The measurements are frequently applied in order to determine particular physical mechanical properties, or as defectoscopy methods for materials and constructions.

3 Site Investigation

A first step in site evaluation is detailed visual examination of the structure to assess its overall condition and to seek broad clues conceming the severity and possible causes of the damage.

In practice, manifestations of structural deficiencies may be obvious or difficult to detect. Attention should be concentrated on examining rectilinearity of the struc-ture and its apertures. Any rotation or translation of the structure should be investigated.

Distress in the major structural components as evidenced by cracking, spalling or bowing should be noted. Deficiencies providing access to water should be sought, since water penetration can have serious deleterious effects on structural components.

Some of these external deficiencies can be detected by visual examination. More precise observations may be obtained using a variety of measuring non destructive testing instruments described in the following contents.

Fig 1. *The author at site investigation*

4 Visual Inspection

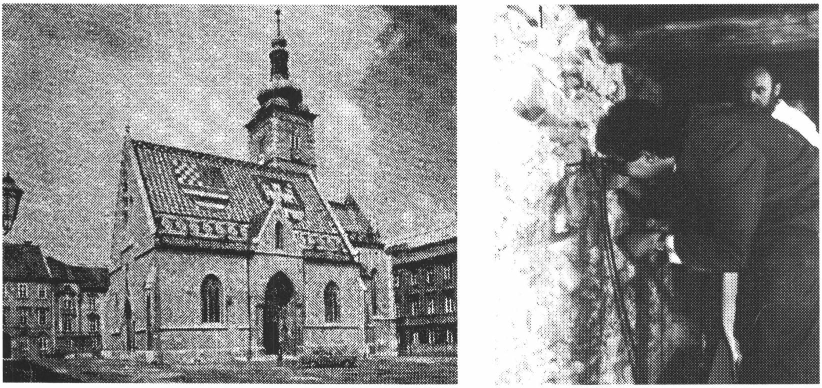


Fig 2. *Visual inspection of the St Marc 's church - Croatia (XIV c.)*

Visual inspection's nondestructive testing technique's are most widely used method"s for detecting surface cracks, which are particulary important because of their relationship to structural failure mechanisms. The methods of monument visual inspection involve a wide variety of equipment, ranging from examination with the naked eye to the use of interference microscopes for measuring the depth of scratches on sculpture surfaces. The equipment used to aid visual inspections includes:

- permanent visual records in the form of photograps, videotapes or computerenhanced images (Architectural photogrametry)
- Flexible or rigid endoscopes (borescopes) for illuminating and observing internal, closed or otherwise inaccessible areas.
- Magnifying systems for evaluating surface microstructures.

4.1 Photogrammetry

Fig. 3. *Photogrammetry of the cathedral in Zagreb - Croatia (oldest part XII c.)*

In architectural photogrammetry, instruments, material and methods must be adapted according to the monument and to the kind of plans which one wants to prepare. In examining the merits of every restitution method we will have to keep in mind that the scope of modem photogrammetric surveys is to give the real form of the monument at the time when the photograph was taken.

A product of photogrammetric restitution can be in: graphical, photographical or digital form.

The graphical form is the most common form and it consists of continuous lines, together with the phographical forms it can give an entire image of the monument. The digital restitution, on the contrary, is not a continuous but a point-by- point restitution. The restitution methods can be divided into two broad groups. The first group consists of methods suited for more or less plane objects using one or many individual photographs. In the second group are the methods that use the photographs by overlapping pairs and that are suitebale for three-dimensional determinations.

In this group stereoscopic methods are used for the observation of photographs. Therefore, we then speak of stereo-photogrammetry. In practice, photographic conditions for recording of monuments and sites only rarely are ideal. Limiting factors are, above all, short camera to subject distances in case of high objects. Often, rows or columns obstruct the view of interiors, or trees cover up part of the building to be photographed. Only cameras with an extremly wide angular field are suitable for this type of work (stereo-metric cameras and independent metric cameras).

4.1.1. Stereometric camera application

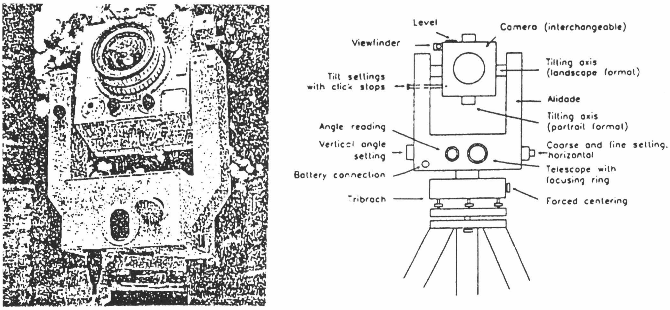


Fig 4. *The stereometric camera (with schematic diagram)*

A stereometric camera consists of two fixed parts relative to each other with usualy, a fixed base. The most common base is 120 cm, for object distances from 5 to 25 m. They are designed for those cases where a simple photogrammetric arrangement is suitable, for example surveys of building facades. The base consists either of a rail with fixed fittings for the cameras at various distances or of a rail along which the camera can be moved and fixed against a scale.

4.1.2. Independent metric camera application

These cameras are used whenever maximum accuracy is required and the base - distance ratio must be carrefully considered. The object distance must lie within the range of the aperture - depend depth of field. The universal metric cameras have exchangeable lenses of different focal lengths and can be focused in both way's. The smal, ligth cameras can also be mounted on a theodolite telescope.

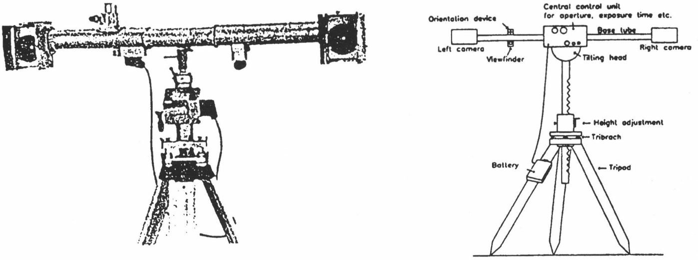


Fig 5. *Independent metric camera (with schematic diagram)*

4.1.3. Requirements in mon. photogrametry

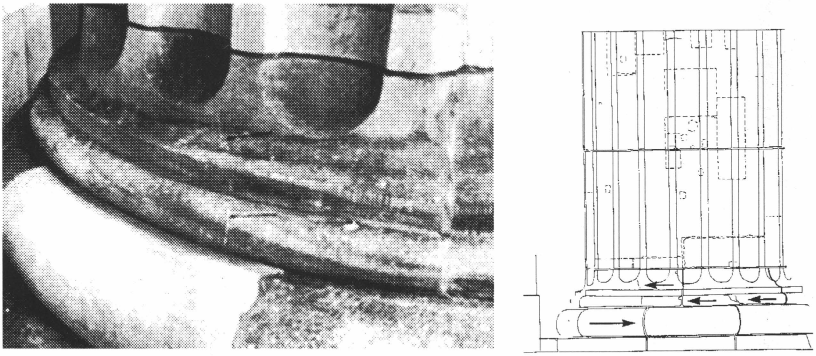


Fig 6. *Photogrammetric evaluation of cracks*

In order to determine the elements of outer orientation, to check the extent of the photographs and to measure the coordinates of control points, a photogrammetric camera should be:

- interchangeable (forced centering) with the theodolite and targets.
- easily levelled on a tripod.
- capable of being swung horizontally through angles which can be read on a horizontal circle or through fixed angles defined by click-stops. A sighting telescope which can be tilted vertically is needed for sighting to points outside the horizontal plane.
- capable of being rotated about the optical axis if photographs of both landscape and portraits formats are required or if an asymmetric image format is to be used to the full.
- provided with a viewfinder, matt screen or marks on the outside of the camera which define the edge rays

The following photographic conditions should be satisfied for the best results:

- external exposure meter
- free choice of aperture and exposure time
- ability to focus on various (calibrated) object distances.
- synchronised shutter release of at least two cameras for simultaneous photographs of a moving object
- largest possible film or plate format
- possibility to use rollfilm and cassetes
- vacuum or pressure plate for film flattering.

Finally, the photogrammetric cameras should satisfy the general requirements of field-survey instruments, such as ease of transport, wheather resistance and so on.

Photogrammetry, as illustrated in this chapter, has proved an efficient means of accurately recording of architectural documentation of buildings and damage to buildings, for preserving cultural assets by photographic records, which can be used at any time and for archaelogical documentation and surveys of excavations.

4.2. Endoscopy

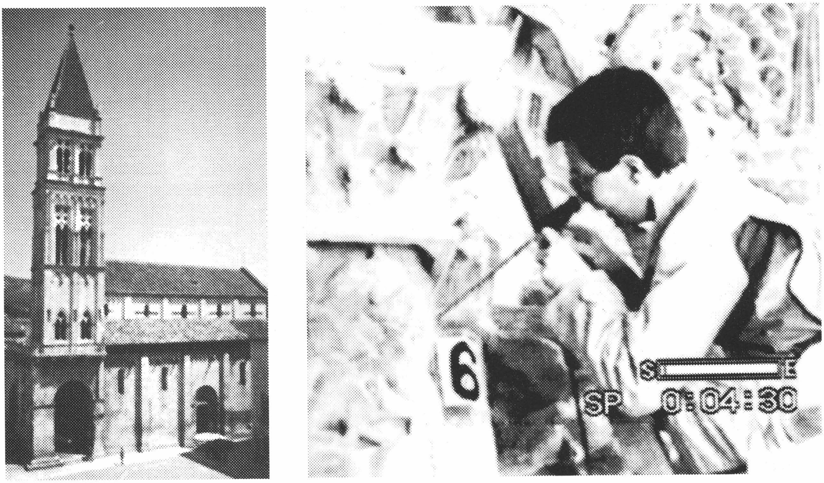


Fig 7. *Endoscopic investigation of the cathedral in Trogir - Croatia (XIII c.)*

A endoscope or borescope is a long, turbular optical device that illuminates and allows the inspection of surfaces inside narrow tubes or difficult-to-reach chambers. The tube, which can be rigid or flexible with a wide variety of lengths and diameters, provides the necessary optical connection between the viewing end and an objective lens at the distant, or distal tip of the endoscope.

This optical connection can be achieved in one of three different ways:

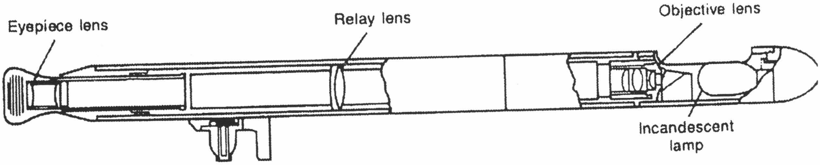


Fig 8. *By using a rigid tube with a series of relay lenses*

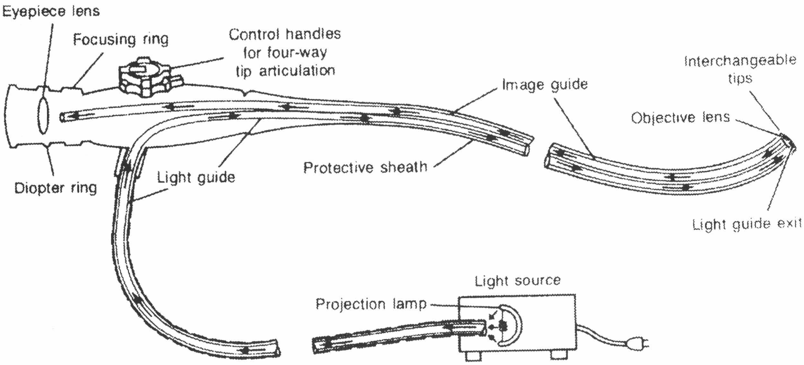


Fig 9. *By using a tube (flexible but also rigid) with a bundle of optical fibers*

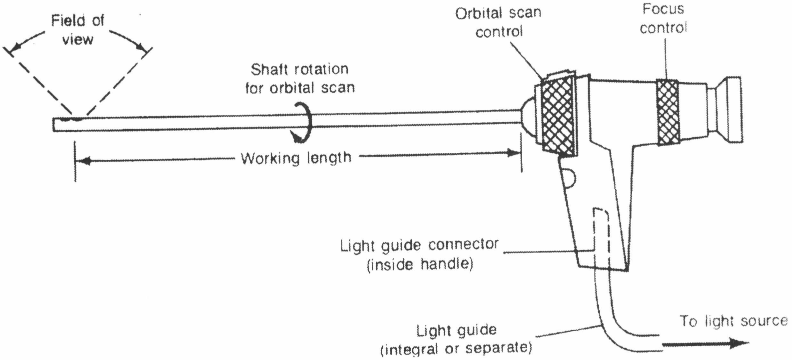


Fig 10. *By using a tube (normaly flexible) with wiring that carries the image signal from a charge coupled device (CDD) imaging sensor at the distal tip*

These three basic tube designs can have either fixed or adjustable focusing of the objective lens at the distal tip. These views vary according to the type and application of endoscope. Generally, a fiber optic light guide and a lamp producing white light is used in the illumination system and light-emitting diodes at the distal tip are sometimes used for illumination in videoscopes with working lengths greater than 15 m.

4.2.1. Examination of wooden and masonry structures

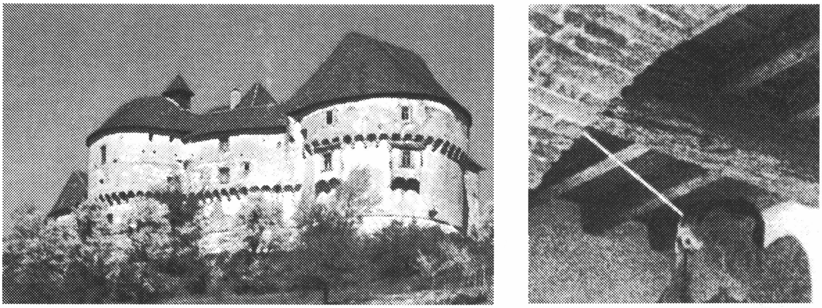


Fig 11. *Endoscopic wooden ceiling structure exam. of the Great Tabor castle- Croatia (XIV c.)*

Priority tasks of the endoscopic investigation is to examine the ceiling structures of old buildings and historical edifices. Especially in areas of possible moisture concentration, intensive examinations must be carried out.

Essential points of inspection should be the basement ceiling and the last ceiling beneath a roof due to the risk of moisture possibly soaking by leaky roof. Wooden beams are often rotten on vaults of top ceilings because of lack of ventilation. This problem does not arise with normal ceilings because the porosity of the adjacent material enables sufficient ventilation. In most situations, it is sufficient to make 10 endoscopic investigations for 100 mm. Photos (see Fig. 12) or video documentation are necessary in critical places.

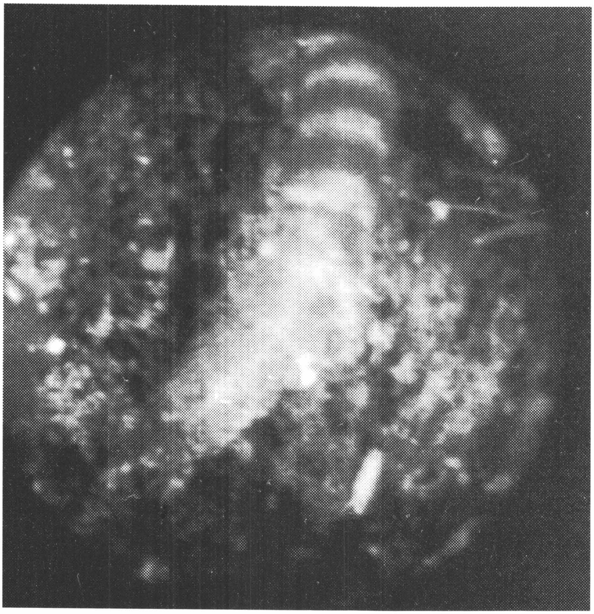


Fig 12. *Endoscopic picture of the wooden Parquet beetle larva (Luctus sp.)*

4.2.2.1. Examination rules

For the examination, the following rules are important to achieve a good picture quality of the photo documentation, especially in wooden joist ceilings:

- The investigated hollow space should not be too large in order to achieve good picture quality without loosing light intensity.
- The object distance should not be too small because this could lead to partial overexposure.
- Remarkable good result can be attained with colour films with a sensitiveness of 200 ASA or black and white films XP1 400.
- The lens system should be protected against any dirt.

Nowadays, the application of endoscopy on monumental structures simplifies the detection of failures and definings of constructions morphology's.

4.3. Magnifying systems

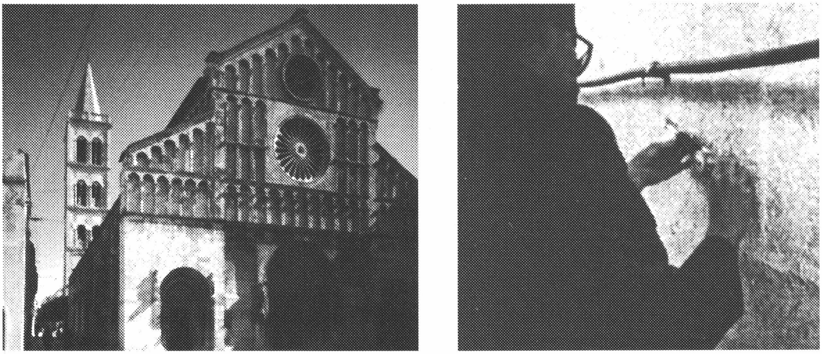


Fig 13. *Magnifying investigation of the cathedral in Zadar - Croatia (XII c.)*

For the width and the movement measurement of cracks caused by, e.g. loading or changing temperature and moisture the magnifying systems ('toolmakers' microscope and dial gauge) are used.

4.3.1. Microscope measurements

When the tolerances are too tight to judge by eye alone, optical 'toolmakers' microscopes are used to achieve magnifications ranging from 5 to 500 x.

A toolmakers microscope consists of a microscope mounted on a base that carries an adjustable stage, a supplementary lighting unit and a micrometer barrel incorporated into the stage position. The use of the toolmakers microscopes is now rapiclly in creasing in restoration purposes.

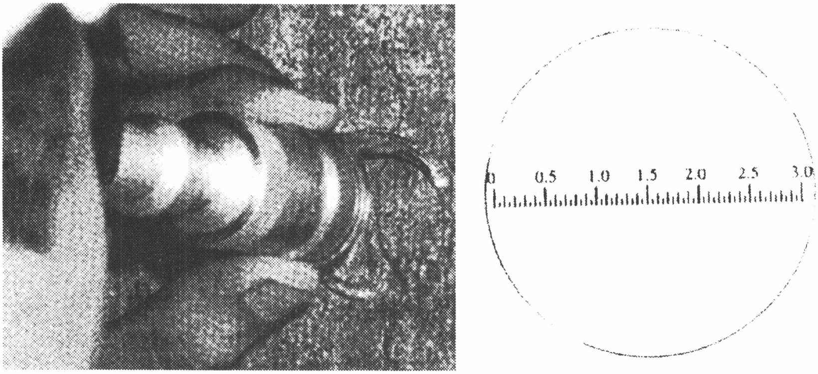


Fig 14. *Microscope crack measurement*

4.3.2. Dial gauge measurement

This system is developed as an advanced system of the 'stick on glas' crack measurement (which is too depended on temperature changes and therefore very often an unreliable indicator). The dial gauge unit is glued to the surface with the measurement points positioned opposite to the crack (see Fig 13). The deformations may be determined within 0.005 mm accurancy. The change of distances between the two points is transformed into the crack opening/ closing diagram.

5. Ultrasonic Inspection

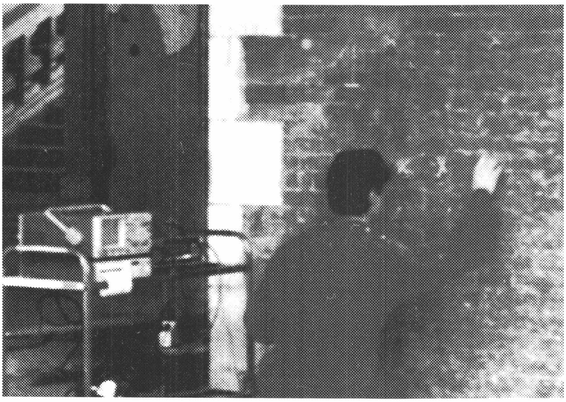


Fig 15. *Ultrasonic investigation*

Ultrasonic inspection is a nondestructive method in which beams of high-frequency sound waves are introduced into materials for the detection of flaws in the material. The sound waves travel through the material with some attendant loss of energy (attenuation) and are reflected at interfaces. The reflected beam is displayed and then analyzed to the presence and location of flaws or discontinuties. The degree of reflection depends largely on physical state of the materials forming the interface and to a lesser extent on the specific physical properties of the material. Cracks, cavities, disbonds and other discontinuities that produce reflective interfaces can be detected.

Most of the ultrasonic inspections are done at frequencies between 0.1 and 25 MHz, well above the range of human hearing, which is about 20Hz to 20kHz. The Ultrasonic waves are mechanical waves (in contrast to, for example, light or electromagnetic waves) that consists of oscillations or vibrations of the atomic or molecular particles of a substance about the equilibrium positions of these particles. Ultrasonic waves behave essentially the same as audible sound waves. They can propagate in an elastic medium, which can be solid, liqued, or gaseous, but not in a vacuum.

5.1. Examination of wooden structures

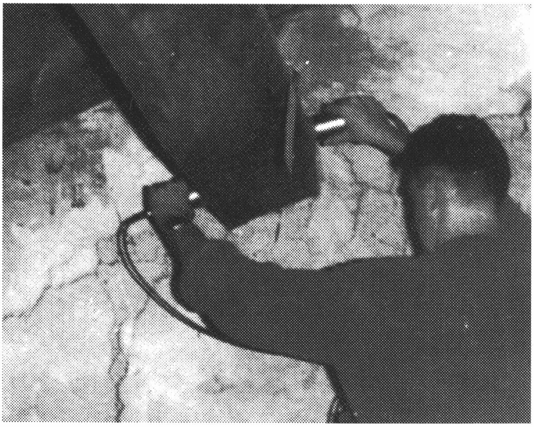


Fig 16.

Ultrasonic Examination of wooden beams in the Opeka castle - Croatia (XVIII c.)

When surveying any historic building, built with stone or brick and timber, it is very important to detect timber decay. Sometimes it is impossible to obtain enough information through the inspections to the building, considering that we usually can't remove parts of the furniture, floors and fittings. Ultrasonic devices are being applied to find a solution to this problem, measuring velocity of propagation, in relation to the reduced section of the damaged material.

5.1.1. Instrumentation

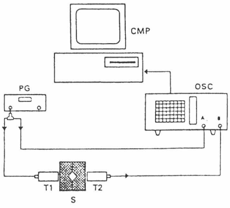


Fig17. *Measurement set up*

The exciter transducer (T1) is driven by an electric pulse produced by the generator (PG). and induce ultrasonic waves through the construction. The transducer receptor (T2), receives the vibrations at the output of the sample. The two-channel digital oscilloscope allows a simultaneous recording of both signals, which are the exciting pulse applied to the T1 transducer and the resulting signal received by the T2 transducer. The signals registered by the oscilloscope are transferred to a computer.

The evaluation of results is obtained by comparing the undamaged parts with the damaged parts of the wood (see chapter 5.2.3.). From the observation of temporal signals of wooden samples, considered in relation to the fraction of holes of each sample, we make a frequency analysis of such signals, giving information about the presence of holes in the wood constructions (the larger the percentage of the holes, the larger the attenuation of the ultrasound signal).

5.2. Examination of stone structures

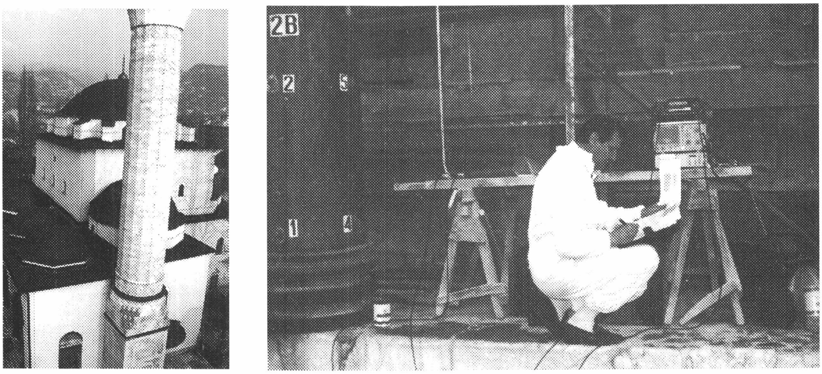


Fig 18. *Ultrasonic testing of the Gazi Husrevbeg Mosque Sarajevo - Bosnia Hercegovina (XIV c.)*

The ultrasonic method uses the propagations of the sound pulse inside the stone elemements and measures the propagation time of the pulse [t] in the distance [s] between the emitting and the receiving transducers, which are in contact with the surface of the stone. The propagation speed measured as $V = s/t$. is a function of the elastic features and the strength of trial medium (Almesberger 1991). This method allows an investigation of the material homogeneity and degration it (surface breaks, cracks depth, cavities etc.). For practical application three different trial methods can be used according to the reguired kind of control and the nature of investigated alterations and flaws (surface, indirect and direct measurement).

5.2.1. 'Surface' and 'indirect'measurements

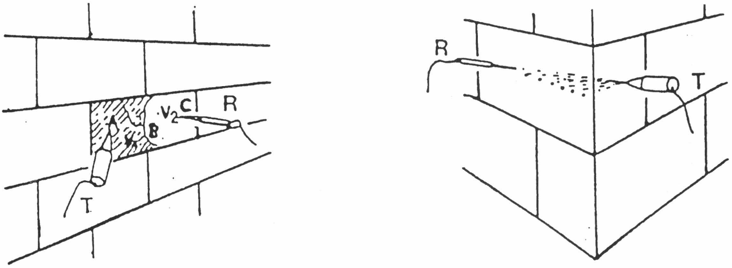


Fig 19. *Surface and indirect measurements*

The 'surface' and indirect (the transmitter and receiver transducer are located under the angle of 90g relating one to the other) measurement technique's makes it possible to detect surface alterations of the stone and determine the size of possible breaks (damaged surface layers) and cracks. This is done by means of interpretation of diagrams representing the sound propagation time as a function of distance between transducers and by applications of relevent analitical methods.

5.2.2. 'Direct' measurement

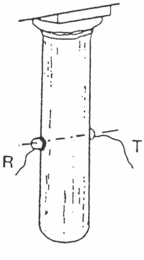


Fig 20. *Direct measurements*

With this measurement it is possible to investigate thc material from the inside through its whole thickness, by putting, the transducers on the two opposite facets and by detecting the presence of heterogeneities within the examined thickness.

5.2.3. Measurement evaluation

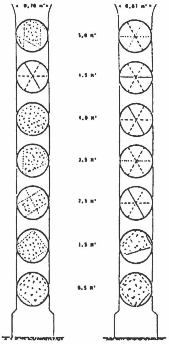


Fig. 21. *Measurement evaluation*

The evaluation of results provided by the above mentioned methodology's is usually made by comparing the undamaged parts with the damaged parts of the stone. The comparison of speed values and visualization of sound waves on the oscilloscope allows qualitative determination of the material degration. For this method "calibration" samples must be available, to determine the elastic dynamic modulus [Ed] and the Poisson ratio [v] as a function of the material density [p], as well as to estimate the mechanical compressive strenght of the material.

The value of the elastic dynamic modulus (Ed) is usually expressed as follows:

$$Ed = V^2 p (l+v) (1-2v) / (I - v)$$

As far as monuments are concerned the diagnosis consists of drawing a map presenting sound wave speeds on the individual elements by using a grid of measurements spots and then distinguishing the intact element parts from the damaged ones.

The speed result can be influenced by various factors, such as humidity of the material , as well as the impregnation degree due to atmospheric conditions and aggressive enviroments (for ex. salts and carbonation).

The ultrasonic survey allows an investigation of the possible causes of monument degradation and, together with specific laboratory tests on samples, allows to choose the most suitable way of restoring the monuments (technique and kind of material).

6. Thermographic Inspection

Fig 22. *Thermographic investigation*

Each object at higher temperature than OK. is emitting infrared rays. Thermographic apparatuses can establisch very small temperature differences on tested objects and convert such radiation (infrared) into a electric signal which is mostly afterwards treated as video-photograph. Different thermic conductivity for different building materials gives different intensity and radiation in the phase of cooling.

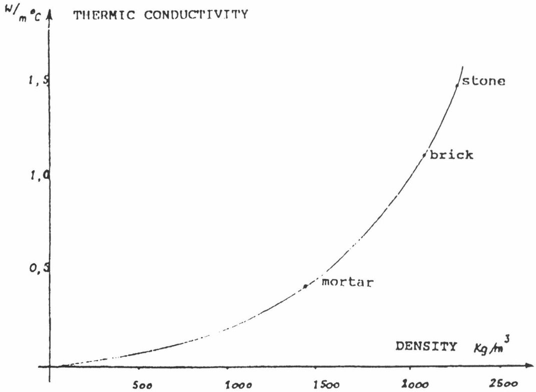


Fig 23. *The change of the thermic conductivity*

(depending on the density of the mortar, brick and stone)

There are different ways in which infrared equipment can be used for termographic investigation depending on the specific application which is envisaged. We can say that thermography can be deployed either in passive or an active fashion.

6.1. Passive approach

The passive approach tests materials and structures which are naturally at a different temperature than the ambient (see Fig 23). Maintenance is an important field of application for infrared thermography where abnormal temperature profiles indicate a potential problem. On the monumental buildings is this application used for moisture evaluation of walls and roofs. In this case thermographic inspection is performed mostly at night (a big disadvantage of this system) and the detection is based on the fact that moist areas retained day sunshine heat better than sound dry areas because of the high thermal capacity of water.

6.2. Active approach

The active approach requires an external heat source to stimulate the materials to be inspected. This is for instance, the case with vibrothermography, where under the effect of mechanical vibrations (20 to 50 Hz) induced externally to the structure, heat is released by friction precisely at locations where there are defects such as cracks and delaminations. The temperature of the materials changes rapidly after the initial thermal perturbation because the thermal front propagates, by diffusion, under the surface and also because of radiation and convection losses. The presence of a defect reduces the diffusion rate so that when observing the surface temperature, defects appear as areas of different temperatures with respect to surrounding sound areas once the thermal front has reached them. Consequently, deeper defects are observed with a reduced contrast. In fact, the observation time t is a function (in a first approximation) of the square of the depth z (Gelo 1987) and the loss of contrast c is proportional to the cube of the depth (Allport and Mc Hugh 1988).

$$t = \frac{z^2}{\partial} \quad \text{and} \quad c = \frac{1}{z^3}$$

where ∂ is the the thermal diffusivity of the material. These two relations show the limitation of the thermographic examination. An empirical rule says that the radius of the smallest detectable defect should be at least one to two times larger than its depth under the surface (Taylor 1982).

6.3. Instrumentation

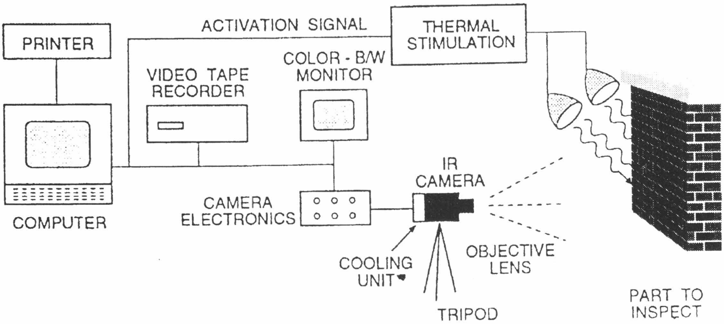


Fig 24. *Thermographic instrumentation*

A system used for thermographic inspection and based on principles presented in the previous chapters must be composed of many different subsystems (Spiro and Schlessinger 1989) such as the infrared (IR) camera, the image acquisition and analysis system and the thermal stimulation system (Fig. 25)

When quantitative analysis is required, an infrared radiometer is necessary. The difference between such an instrument and an ordinary infrared camera is that, for the radiometer, the infrared signal is temperature calibrated thanks to the presence of internal temperature references seen by the detector elements during the image formation process. This calibration signal allows recovery to the absolute temperature after proper processing In this instrument, the image is electromechanically scanned over the detector surface by means of the synchronous rotation of mirrors or prisms (Fig.26).

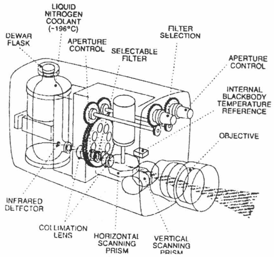


Fig 25. *Internal view of an infrared radiometer*

To accommodate the standard video signal format of 25 frames per second, a very high scanning rate is required. This imposes a wide bandwidth from the associated electronics for the noise level to be kept small. To overcome this problem, some manufacturers use slower scanning rates and have frames made of several fields with one field update at each scan (e.g. 4: 1). As a result, the output obtained, comprising several fields, is not updated in real time (that is at 30 or 25 Hz). This may cause problems when fast thermal events must be observed since thermal information registered at different times is mixed together. One way to solve this problem is to split the video signal into its basic fields and process them, knowing the time interval between each (Shepard 1991). However, this kind of analysis requires careful manipulation of the signal. If a radiometer is not available, it is still possible to perform quantitative investigations with an infrared camera (e.g. based on a pyroelectric vidicon tube) at the condition to place a known temperature reference source in the field of view. This may not always be possible for example, in the case of distant objects or restricted fields of view.

Various lenses and expansion rings can be mounted in front of the IR camera in order to accommodate a specific field of view. Expansion rings or tubes inserted in the optical path between the objective and the camera permit achievement of greater magnification. Care should be taken to the geometric distortions and the vignetting effects which are likely to occur when high magnification is used. Proper calibration is necessary to correct these effects. Nowadays, the application of thermography is mostly used for thermal insulations evaluations. On monumental structures it simplifies the defining of wall morphology, hidden channels and openings, plaster breaking of the wall moist places and erroneus places of hidden frescoes.

7. Radar Inspection

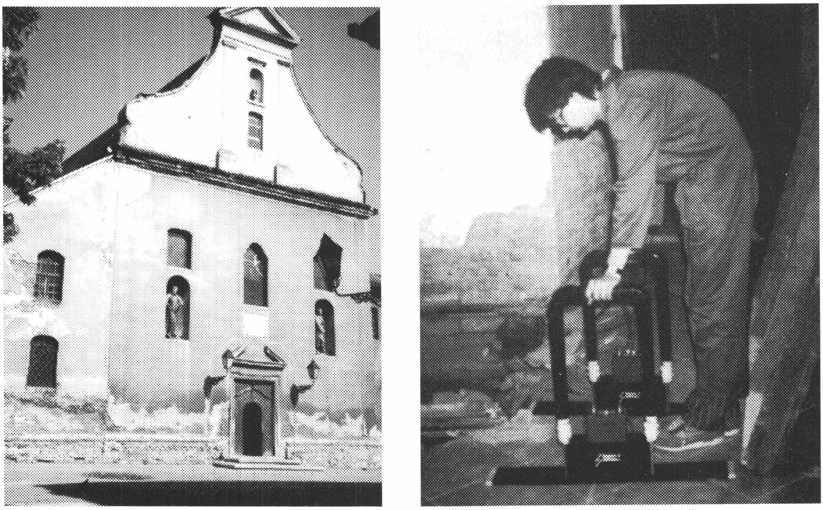


Fig 26. *Radar examination of the Franciscan Monestery in Osijek - Croatia (XVIIIc.)*

If in a glass ballon under vacuum, by considerable velocity electrons are directed to collide with a metal disk, it produce an emission of electromagnetic waves (so called X-rays).

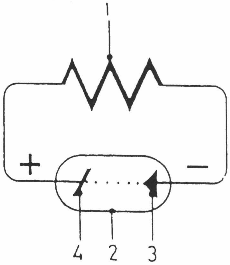


Fig 27. *Principle of an X-ray generator*

1) high voltage (HV) generator; 2) vacuum tube; 3) electrons generator (cathode), metal target (anode). the marked points between electrodes represent the electrons that accelerated by the electric force (HV) bombard the anode and produce x-rays.

Radar technology employs the principle of electromagnetic radiation and is governed by the wave propagation theory.
In general the radar system has a non-directional antenna that transmits a short burst, typically 1.5 us, of radio frequency energy into the material. The energy wave is transmitted in all directions and is reflected whenever there is a change in the electrical properties of the material. The collected data are stacked and integrated to reduce noise from background information. The radar system frequency is determined by the octave of the used band-width antennas. The lower the frequency of the antennas, the deeper the waves tend to penetrate, and the higher the frequency, the better the resolution between changes of materials. For the detection, center frequencies of about 500 MHz, 900 MHz and 1 GHz are used. The resolution is approximately one-half the pulse length so that at 1 GHz the radar can resolve the reflection from the surfaces of layers as thin as 100 mm in building materials. Thus the combination of frequencies is beneficial for a typical wide range of objec-tives: the 500 MHz system is useful for measuring the total wall thickness, and the higher frequencies, namely 900 MHz and 1 GHz, can be used for detecting the cladding layer thickness, voids and moisture (affecting the radar response image simultaneously) in different building components accesible from one side only.

For the sake of facilitating the process of analysis, it is very useful to acquire prior information before measurement such as boundary condition, geometrical and electromagnetic properties of the constituents (see chapter 7.1.1.).

7.1. Archaelogy-application of ground penetrating radar

Fig 28. *Archeological radar investigation of the castle Old town Ozalj - Croatia (oldest part XIII c.)*

The ground penetrating radar is the general term applied to a special radar technique which employs radio waves to map structures and features buried in the ground. This technigues therefore very useful by archaelogical examinations of metal elements and walls (see Fig 29).

7.1.1. Examination rules

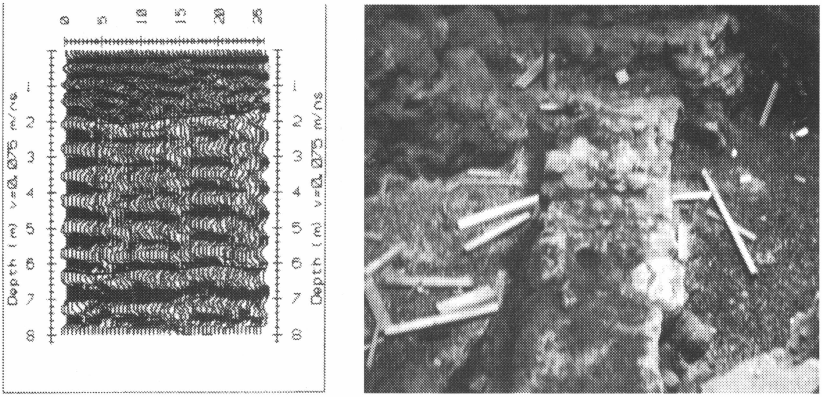


Fig 29. *Detected underground medieval wall.*

The most important in a ground penetrating radar (GPR) survey is to clearly define the problem. this step is not unique to radar examinations but common to all non destructive testing althought often overlooked in the urge "to rush off and collect data".

There are five fundamental questions to be answered before deciding if a radar survey is going to be effective:

- 1) the target depth

The answer to this questions is usually the most important. If the target is beyond the range of a radar in ideal conditions it can then be ruled out as a viable method very quickly

- 2) the target geometry

The target to be detected should be qualified as accurately as possible. The most important target factor is target size (i.e., height, lenght, width). If the target is nonsperical, the target orientation (i.e., strike, dip, plunge) must be qualified.

- 3) the target electrical properties

The relative permittivity (dielectric constant) and electrical conductivity must be quantified. In order for the radar method to work, the target must present a contrast in electrical properties to the host environment in order that the electromagnetic signal is modified, reflected or scattered

- 4) the host material

The host material must be qualified in two ways. First the electrical properties of the host must be defined. The relative permittivity and electrical conductivity have to be evaluated. Second, the degree and spatial scale of heterogeneity in electrical properties of the host must be estimated. If the host material exhibits variations in properties which are similar to the contrast and scale of the target, the target may not be recognizable in the myriad of responses (commonly referred to as volume scattering) generated by host environment

- 5) the survey environment

The GPR method is sensitive to surroundings in which measurements are made. Two important factors are the presence of extensive metal structures and /or radio frequency electromagnetical sources. Another aspect of the examination is the accessibility. Can the equipment and the operator get to the area of interest safely and economically.

The primary radar examination objectives are to indentify the characteristic of stone masonry walls, thickness of materials, voids, condition of mortar fill, etc.

8. Monumental monitoring system (MON)

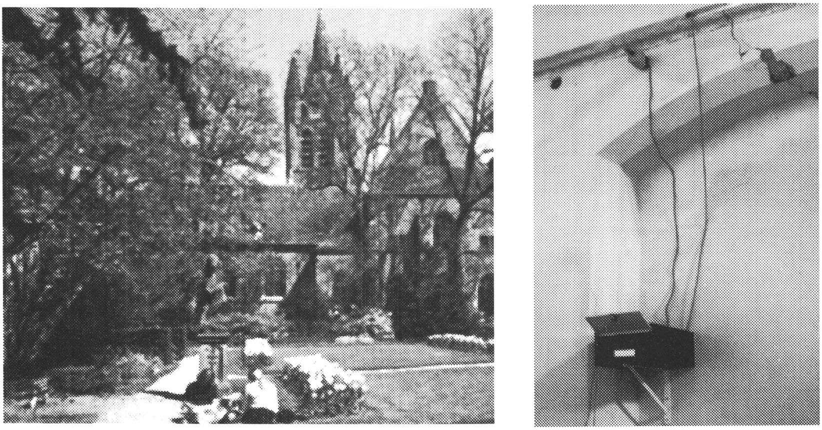


Fig 30. *Continuous monitoring of the Old Church in Delft- The Netherlands (XIIIc.)*

Maintenance of historical and monumental buildings is a general and serious problem requiring considerable costs to find out the reasons for degeneration occurence to plan the most effective repair and to realize it successfully. Such problems can be solved by continuous monitoring, because in this way the development of fissures can be observed, thermohygrometric conditions, relaxation of constructions and first of all the protection in case of developed decay of a construction which can lead to the loss of its stability.

In mechanical engineering periodic inspections of structures like high-pressure boilers or similar systems have been performed for more than one hunderd years. Permanent inspections are widely in use. A similar system of supervision and maintenance was installed 25 years ago in Japan for the buildings of the " Shinkansen " - highspeed line. Monitoring of monumental buildings follows the basic ideas of the two examples mentioned above.

8.1. Aimes and strategies of monument monitoring

The benefits of an monument monitoring system should be:

- Early warnings in all cases of severe damages.
- Parts of the building, which are not easy or even not at all accessible can be controled and inspected in all periods of the year
- More reliable statements than a purely visual inspection can be obtained

It can be assummed that the overall costs of an inspection and also the maintenance costs will be reduced by a proper choice and instalation of sensors.

8.2. Elements of a monument monitoring system

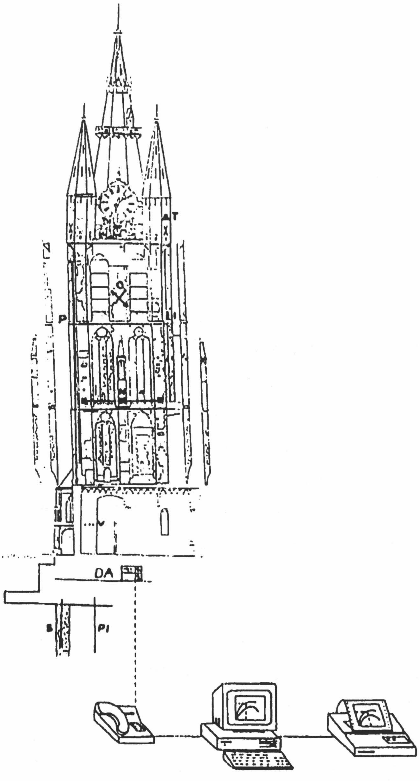


Fig 31. *Continuous monument monitoring system sheme*

The monitoring System consists of:

- sensors (T- temperature, V- humidity, I- inclination, P- pendulum, N- level movement, S - foundation settlement, P- underground water level)
- data acquisition unit (D A) and connections (connecting lines and modems)
- evaluation

The arrangement of these elements, the number of sensors and type of acquisition may be quite different, depending on the extent and the aims of the task.

8.2.1. Sensors

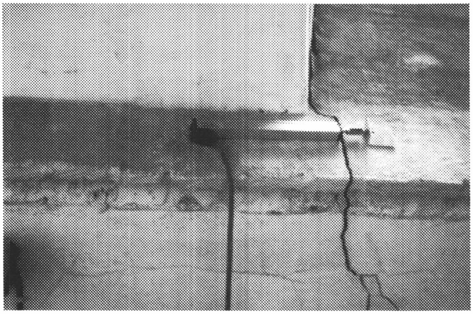


Fig. 32. *Crack meter sensor*

In order to examine quality criteria and evaluate them in quantitative terms, a system of measured variables featuring the following elements has to be established. An Assessment criterion measure which allows the respective quality characteristic to be quantified and a suitable method of measurement is necessary. The sensors have a key role in this context. A sensor is a method or a measuring instrument by means of which the characteristic to be examined can be reliably detected.

By using sensors which can convert physical phenomena such as temperature, force, sound, pressure, light, and position to a measurable electrical quantity, such as voltage or current, it is posible to follow the evolution of structural cracking, termo hygrometric conditions, structural displacements and other sources of material and structural deterioration occuring within a time domain (see fig 31).

By developing a data acquisition unit you must have a reasonable understanding of the limitations of the sensor signals to be processed. The following questions have to be solved:

- kind of signal (dc, quasi-dc or dynamic)
- dynamic range
- frequency range
- noise characteristics and
- shape of the frequency range

These questions , along with the information to be acquired, are fundamental to the design of a data acquisition system.

8.2.2. Data acquisition

The data acquisition unit of the monument monitoring system (MON) is developed to measure the analog inputs, translate the results into the digital domain, store the data for future processing and analysis. The information may then be transferred through a modem and a telephone line to the controling computer.

The display on the unit enebles instantaneous sensor readings to be viewed. In the following chapters the main data acquistion element funcktions are described.

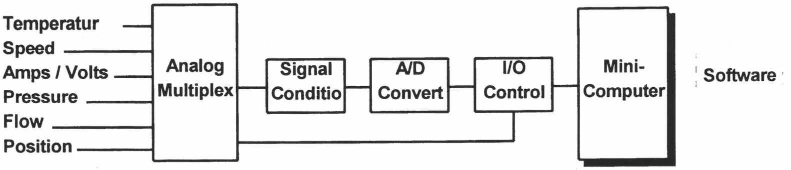


Fig. 33. *The Data Acquisition System - Block Diagram*

8.2.2.1.Analog multiplexer

The analog multiplexer permits a number of signals sources to be automatically measured by the same data acquisition hardware. It consists of a series of switches whose inputs are tied to the various analog signals and whose outputs are tied to a common measuring point. Each input is individually connected to the measuring point in a predeterminated sequence. The number of channels in a multiplexer may vary from two to several hundred.

8.2.2.2.Signal conditioniring

Very often the signals presented to the inputs of the data acquisition system are not in a form appropriate for conversion, and so they most be preconditioned. The required signal conditioning could consist of linear amplification, logaritmic amplification, filtering , peak detektion or sample -and-hold . Often more than one of these functions is required. For instance, it is not uncommon to combine amplification with filtering or to find aq. low-level amplifier before a sample-and-hold.

8.2.2.3. Analog to digital (A|D) converter

The analog-to-Digital converter actually translates the analog signal into an encoded digital format. Of the numerous ways to perform this function, only about a half dozen techniques have found wide acceptance. Most notable are the dual-slope integrating and the succesive approximation converters. A/D converters are often referred to by the number of output digits they produce. In a binary system, the range is from 4 to 16 bits, while in a binary-coded decimal system, 3 to 4 digits are normal.

8.2.2.4. Digital clock

The digital clock provides the master timing for the data acquisition system. It may be as simple as a multiphased crystal controlled oscillator, or it may provide the user with a wide selection of multiplexer and modes of operation. Some systems also contain both time-of-day and day-of-year clocks.

The clock information is supplied by the computer and timing is generated in the input/output (I/O) controller.

This system configuration has two distinct advantages: first, on-line programmable processing is possible; and second, a host of storage media is available.

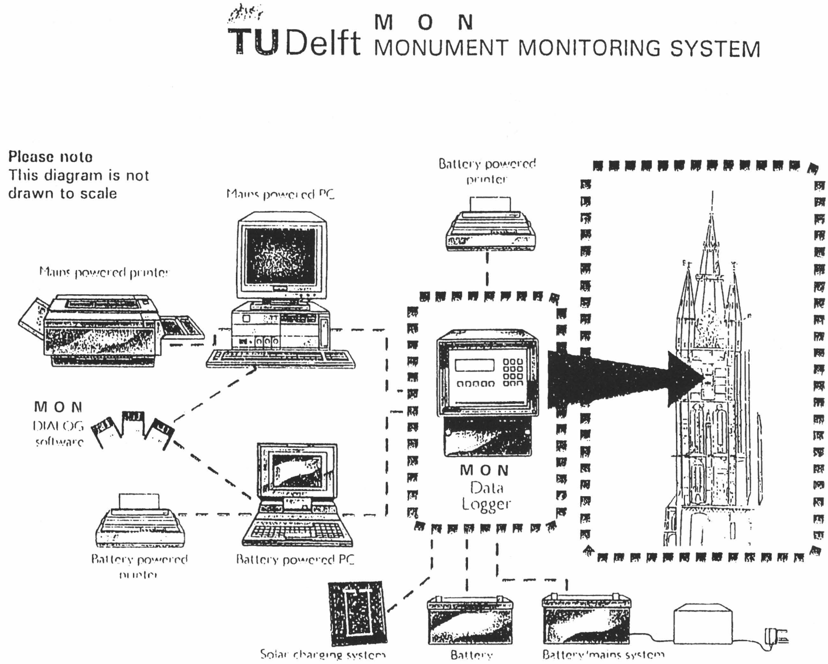


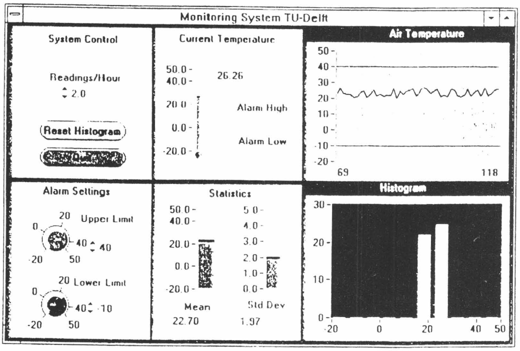
Fig 34. *Monument monitoring system (MON) sheme*

The monument monitoring system (MON) contains a microprocessor (the data is stored in an internal RAM) and the standard system used battery power. Internal data manipulation and alarm facilities (in developing phases) enable the MON system to perform sophisticated monitoring tasks. It can be controled or reconfigured by an connected (direct or through modem) IBM compatible computer (minimum 386sx) runing the MON dialog software. A batery powered printer can be connected directly to the DA unit to produce a table of results without using a computer.

8.2.3. Monitoring result evaluation

Developments in the fields of artistical intelligence and knowledge based systems (KBS) have provided new methods of representing data and opportunities for modelling systems [Comerford and Stone, 1992]. These techniques provide the possibility of extending the use of computers to assist engineers in the intepretation of the data. The monument monitoring (MON) system use such techniques with the aim of improving management of monument safety. This system forms part of a strategy to improve the management of information concerning monuments using the latest software technology to enhance the management of their safety.

The MON data logger (data acquision unit) is the first versatile instrument designed to meet the general logging requirements of monument care specialists in the field of restoration and conservation. Using the dialog computer program MON each cannel of the MON data logger can be programmed so that complex measurements and control routines involving many diferent sensors can be produced. The programmed software front panels are so designed to enable easy control of the multiple instruments and view the entire system as one virtual instrument.



Readings/Hour 2.0

Upper Limit 40

Lower Limit -10

Mean 22.70

Std Dev 1.97

Fig 35. *Virtual Instrumentation*

The logging intervals from 2 times a second to once a day can be selected and the historical data can be retrieved and displayed graphicaly .

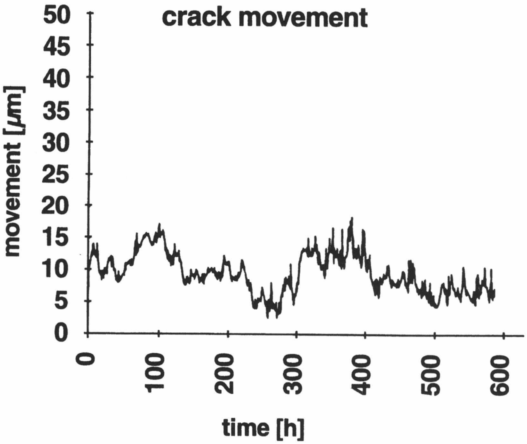


Fig 36. *Crack movement over a period of approximetly one month.*

The intepretation of data requires the use of engineering judgement, knowledge of the particular structure, experience of the behavior of monumental buildings and a background of general engineering knowledge. Of particular importance is a knowledge of what represents normal behaviour of the structure and conversely what constitutes abnormal behaviour of the structure. (it is necessary to set the right alarm limit parrameters) and how this might be manifested in the data. The main tasks are to indicate:

- which individual structures shall be monitored in the future,
- which parameters are the most sensitive ones for an early detection of damages and possible prewarnings.

9. Quality Assurance(QA) programme

To compare the monumental non destructive testing results through a longer period and to improve the control efectiveness a quality assurance (QA) programme is necessary with: calibration procedures, equipment controls (maintenance and calibration controls), operating procedures, document controls (test procedures, test result and test equipment status) and in the future the classification of non destructive examination personnel (similar with metal NDT) in three levels: level I qualified to properly perform specific calibrations and tests; level II to read and interpret the results and level III to establish new applications and techniques. These system provide a way of working that either prevents problems arising or indentifies and deals with them effectively and cheaply if they arise. The emphasis is on 'fire prevention' rather than 'fire fighting'.

10. Concluding remarks

The structural evaluation of heritage buildings encounters difficulties due to the requirement for minimal intervention and to the sparse or non-existing information of their construction.
The described nondestructive techniques have been reported as promising methods to investigate the type, geometry and anomalies of monumental constructions.

In order to get appropriate results, it is neccessary to know and understand the limitations of the applicability of each method and its capability. In many cases, the application of NDT-methods seems very easy, but the intepretation of the results, especially those obtained with **ultrasonic** pulses requires extensive experience for the determination of the mechanical structure characteristics.

Infrared **thermography** is an attractive and relatively unexplored technique for the non destructive evaluation of failure in structures. The main advantages of this technique are speed and non contact operation. Signal processing techniques might efficiently used to extract more quantitative information. It is of particular interest that the method allows not only qualitative work such as finding flaws, defects or weakness zones, but also quantitative analysis of the effects of flaws and defects on strength and durability of structural components (specially by wooden constructions). This useful technique offers accurate ilustration of crack initiation, the onset of its unstable propagation through the material and flaw coalescence when increasing irreversible micro cracking is generated by cyclic loading. Significant developments are expected soon, capitalising on the recent progress in computing power and image processing techniques.

The investigations have shown that **radar** is in general suitable for examining the structural properties of building elements. Inhomogeneities of the surface element to be examined have hardly any influence on the measurement result. Areas where the materials properties change drastically can easily be identified.

The **continous nondestructive monitoring** of historical monuments appears as an effective preventive measure, especially in case of advanced deterioration of a structure which can lead to a complete loss of its own stability. Monitoring is therefore not only useful but in fact an essential technique for safety of structures and their users.

The non destructive testing creativity is not a matter of knowing special creativity techniques, but of adopting the right approach, possesing a comprehensive know-how which includes boundary areas, and taking sufficient time to deal with the problems in detail. The conflict arising through the need to optimize work procedures **(quality assurance - QA)** on the one hand and to foster creativity on the other hand must be given due consideration. I am confident that we will experience more innovations in testing methods over the next 25 years than during the past 100 years. To be on the edge of this progress we must set the course today.

Antoine de St. Exurpy once said: "It is impossible to foresee the future, but one can lay the foundation stone for a future thing, because it is possible to build the future".

11. Bibliography

D. Almesberger, " Monitoraggio per la Diagnosi dell Affidabilita residua di Monumenti in Muratura ", 4 Ciclo di incontri professionali ristrutturazione edilizia techniche e costi, Torino 1991

D. Almesberger, I. Smotlak " Ultrasonic Measurements in Diagnosis of Stone Monumental Structures ", International Conference 'Constructors in Renewal', Brioni, 1992

D. Almesberger, S. Heruc, B. Ceizek, " Quality Control of the St. Marc's Church Bell Tower (Zagreb, Croatia) by Means of Endoscopy and Pull-Out Tests ", International Conference 'Constructors in Renewal', Brioni, 1992

S. Chidiac, J.Rainer, L.Davis, B.Johnson, " Use of impulse radar for investigating the integrity of stone-masonry walls ", International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE), Berlin, 1995

J.B. Comerford, J.R. Stone, " Artificial intelligence in risk control ", D.I. Blockley (Ed), 'Engineering Safety ', Macmillan: London, 1992

J.B. Comerford, M. Lazzari, Giovanni Ruggeri, Paolo Salvaneschi, M. Fannelli, G. Giuseppetti, G. Mazza " Damsafe: An Expert System for the Managment of Dam Safety ", International Conference on Monitoring and Predictive Maintenance of Plants and Structures, Firenze, 1992

Conservation of Historic Stone Buildings and Monuments, Report of the Committee on Conservation of Historic Stone Buildings and Monuments, National Materials Advisory Board Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington DC, 1982

R.A. Eberlein, " A Data Acquisition solution ", International Conference on Monitoring and Predictive Maintenance of Plants and Structures, Firenze, 1992

S. Heruc, " Architectural and Building Stone application of Radar Examination ", International Conference ' The Constructors in Renewal ', Brioni, 1992

S. Heruc, " Consolidation of the Bell-Tower of St. Marks in Zagreb by Pressure grouting ", The 11th Conference of the Civil Engineering Associatian, Cavtat, 1991

S. Heruc, " Continues Environmental Non Destructive Testing Monitoring of Historical Monuments ", The 27th conference of The Environmental Design Research Association, Salt Lake City, 1996

S. Heruc " Computerize N.D. Testing Monitoring of Historical Monuments " , European Academic Software Award, Klagenfurt, 1996

S. Heruc, " Continues NDT Monitoring of Historical Monuments ", International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE), Berlin, 1995

S. Heruc, " Die Wigopol - Mauerenfeuchtungssystem (anwendungs beispiel - St. Katarina kirche, Zagreb, Kroatien)" , ' Feuchtetag '95 ', Feuchtigkeit in Mauerwerk, Messen- Berechnen-Trockenlegen, Berlin, 1995

S. Heruc, " Managment processes related to the maintenance of historic buildings in the Netherlands ", workshop: Historical, Modern and Contemporary City- planning in the Netherlands and Japan, Tokyo, 1995

S. Heruc " Non Destructive Protection of Pests in Wooden Monumental buildings ", Wood of Finland - International Competition, Helsinki, 1996

S. Heruc, " Non Destructive Testing Reports No. 1 - 36 ", Zagreb, 1991 - 1994

S. Heruc, " The Inner City Renewal of Dubrovnik ", Final report, Institute for Housing Studies, Rotterdam, 1993

S. Heruc, "The use of Non Destructive Testing Monitoring in Restauration and Conservation of Historical Monuments ", ' Doctorates in Design and Architecture ' Conference of the European Association for Architectural Education, Delft 1996

K. Kraus, " Photogrammetry " Ummler, Bon, 1993

O. Kroggel, " Monitoring of Civil Engineering Structures ", International Conference on Monitoring and Predictive Maintenance of Plants and Structures, Firenze, 1992

X.P.V. Maldague, " Nondestructive Evaluation of Materials by infrared Thermography ", Springer, London 1993

Metals Handbook Ninth Edition, Volume 17 Nondestructive Evaluation and Quality Control, ASM International Handbook Committee, American Society for Testing and Materials.
L.P. Perez, V.G. Llopis, F.C. Moreno, V.M. Hurtado, " Using Ultrasonic Waves for the Detection of Timber Decay in Old Buildings ", International Symposium on Nondestructive Testing of Wood, Washington, 1994

G. Teodoru, J. Herf, H. Adam, " Engineering Society Cologne, its experience with NDT methods in constructions ", International Symposium Non-Destructive Testing in Civil Engineering. (NDT-CE), Berlin, 1995.

Z. Zagorac, S. Heruc, T. Gregl, " Detection of an airplane bomb by geomagnetic testing of the 'Reduit' rook building (XVIII c.) in Slavonski Brod", the Mining - Geological- Petroleum Engineering Bulletin, Tome 6, Faculty of Mining, Geology and Petroleum Engineering, Zagreb, 1994.

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