Heritage Problems, Causes and Solutions

Calogero Bellanca and Susana Mora Alonso-Muñoyerro

University Press

SAPIENZA
UNIVERSITÀ EDITRICE

3

Heritage Problems, Causes and Solutions

Heritage Problems, Causes and Solutions

Calogero Bellanca and Susana Mora Alonso-Muñoyerro

SAPIENZA
UNIVERSITÀ EDITRICE
2023

Under the patronage of

SAPIENZA
UNIVERSITÀ DI ROMA

This book is funded with the resources belonging to Sapienza from the Sustainable Urban Rehabilitation in Europe (SURE), scientific Erasmus + project (2016-2019).

This material is didactic, to be used in education. The graphic material although fundamentally is made by the authors, includes photographs and drawings compiled from material used by the authors in their lessons in ETSAM (UPM) (*Construction and Heritage Courses*), Sapienza University of Rome (*Course of Theory and Practice of Conservation* and *Laboratorio di Restauro*) and other european university.

In this volume have collaborated specially these architects:
Ignacio Mora Moreno, Alejandro Iniesta Munoz, Magdalena Prieto de la Lastra

Sapienza Università Editrice
Piazzale Aldo Moro 5 – 00185 Roma

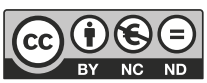
www.editricesapienza.it
editrice.sapienza@uniroma1.it

Iscrizione Registro Operatori Comunicazione n. 11420
Registry of Communication Workers registration n. 11420

ISBN 978-88-9377-262-4

DOI 10.13133/9788893772624

Pubblicato nel mese di febbraio 2023 | *Published in February 2023*



In copertina | *Cover image*: *Colosseum*, detail. Photo by Susana Mora and Calogero Bellanca.

Dedicated to our parents

Maria and Antonino
Consuelo and Justo

Index

PART III – CONSTRUCTION APPLIED TO HERITAGE

CHAPTER 5. DAMAGE TESTS ON MASONRY CONSTRUCTIONS AND SURVEY, MAPS AND TESTS ON WOODEN CONSTRUCTION

INTRODUCTION: THE NECESSITY OF UNDERTAKING TESTS

Following an accurate structural survey and an in-depth and critical historical analysis, it is possible to identify possible extensions, tampering, raised areas, closures and openings in rooms, hidden cavities, shallow or deep lesions, further manifestations of static instability (detachment, rotations, subsidence, sinking, etc.), presence of humidity.

The above cannot always be detected through a simple direct visual examination of the monument by reconstructing the damage or deficiency inside the structures or hidden by the presence of plaster; on the other hand, this type of approach does not always allow to establish with certainty the cause generating the specific phenomenon or the static instability found. As far as the historical-archival analysis is concerned, the limitation may lie in the partial or total lack of documentation, as well as in the difficulties that lie in the temporal reconstruction of the successive construction phases and sometimes overlapping over the centuries. (1)

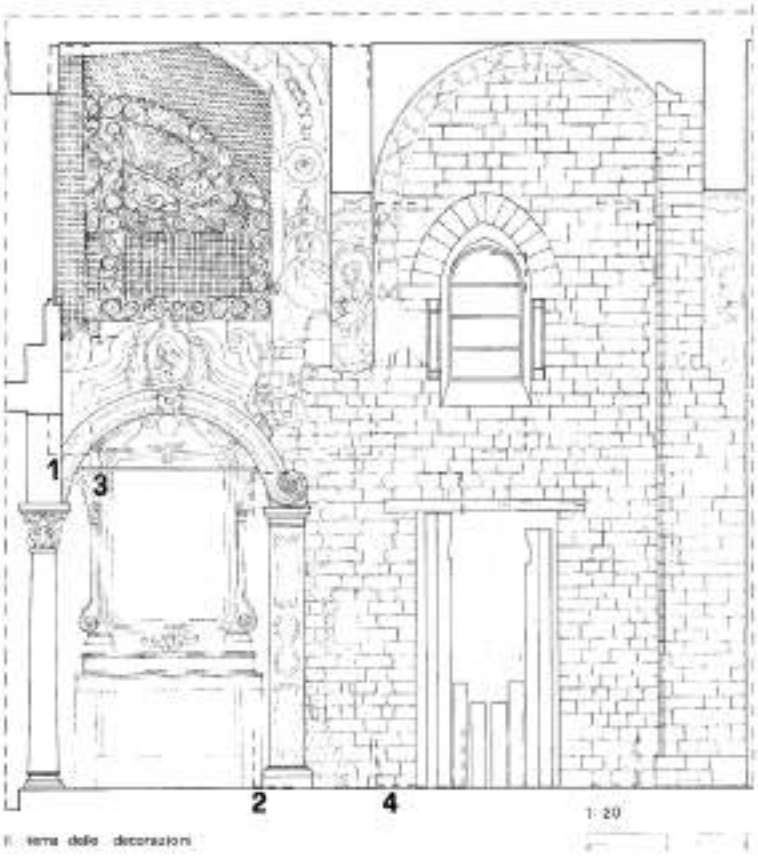
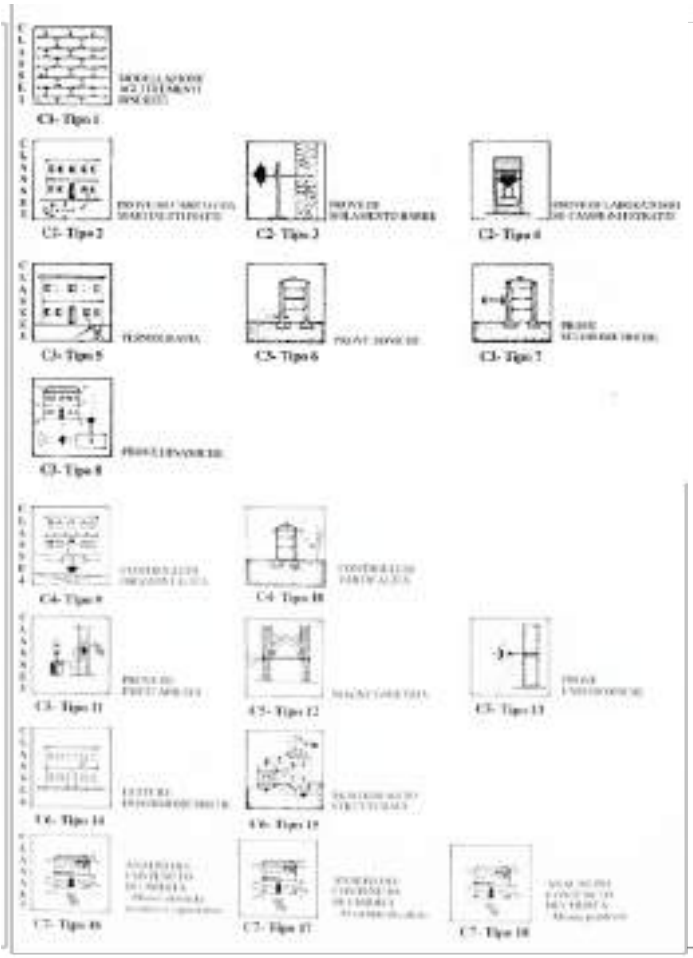


Fig. 1. Church of Santa Maria dell'Ammiraglio 1987. From C. Bellanca (a cura), *Una didattica per il restauro*, Atena Editrice, Roma 2008, p. 60.

STARTING POINT

The starting-point for the planning of the test are the material and mechanical survey and the maps of damage, including the different damage causes (deterioration, mechanical lesions and humidity problems).

MASONRY CONSTRUCTIONS: TEST CLASSIFICATION



Class I	**Theoretical analysis**
type 1	Discrete element modeling
Class II	**Mechanical analysis**
type 2	In situ flat-Jack load test
type 3	In situ bar extraction test
type 4	Sample extraction for laboratory test
Class III	**Quantitative analysis**
type 5	Thermography
type 6	Sonic test
type 7	Sclerometric test
type 8	Dinamic test
Class IV	**Instability verification**
type 9	Horizontality verification
type 10	Verticality verification
Class V	**Elementary tests**
type 11	Instability test
type 12	Magnetometry
type 13	Endoscopic test
Class VI	**Periodic analysis**
type 14	Deformation measure
type 15	Structural monitoring
Class VII	**Humidity content analysis**
type 16	Electric resistence and capacity measure
type 17	Calcium carbide analysis
type 18	Pondering measurement

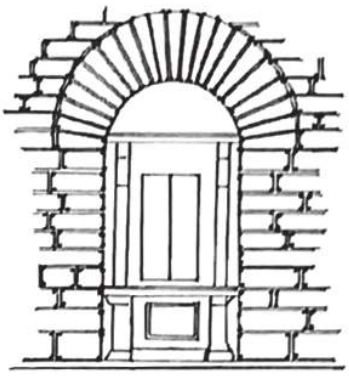
Fig. 2. Masonry Construction: Test Classification. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica,* Edizioni Kappa, Roma 1999, p. 22.

CLASS I: THEORETICAL ANALYSIS

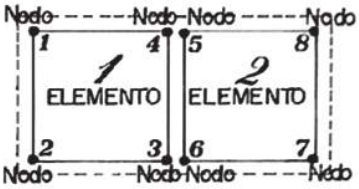
DESCRIPTION

The theoretical analysis with the method of the discrete elements allows to examine systems of structural elements, interacting with each other, without the postulate of the continuity and homogeneity of the constituent material, fundamental assumptions in the analysis of the finite elements, through which the structure is schematised as a continuum composed of a finite number of elements delimited by nodes.

Precisely for this reason, the discrete elements find the most suitable application in the field of masonry composed of blocks of stone or brick and sliding surfaces represented by appeals and mortar joints. Using data from the entire diagnostic campaign to support it, it is also possible to formulate a hypothesis on the behavior of the structure considering the system consisting of a series of bodies in itself whose movements are regulated by the interaction with the neighboring elements.



DISCRETIZZAZIONE DELLA STRUTTURA
UN NUMERO VARIABILE DI ELEMENTI



INDIVIDUAZIONE DEGLI ELEMENTI
DEFINITI DA PUNTI DETTI NODI

Fig. 3. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 45.

EXECUTION

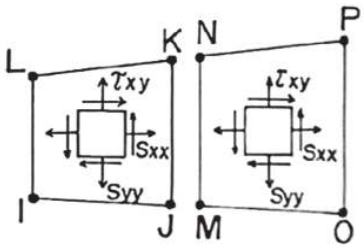
a) Discretization of the structure into single elements delimited by nodes.

b) Following stress the initial contacts between the elements vary mutually; the elements adjacent to each other at the beginning of the analysis can, following displacements and rotations, lose the previous contacts and develop new ones.

c) Forecasting of loading conditions and analysis, by computer processing, of a static or dynamic type.

d) Graphicization of structures discretized by means of "Plotters" in plants, elevations, sections and axonometries.

e) Elaboration of representative diagrams of normal stresses, bending moments and deformed moments.



SOLLECITAZIONI PRESENTI NEI SINGOLI
ELEMENTI

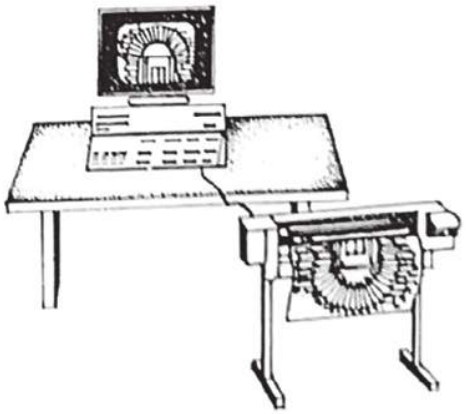


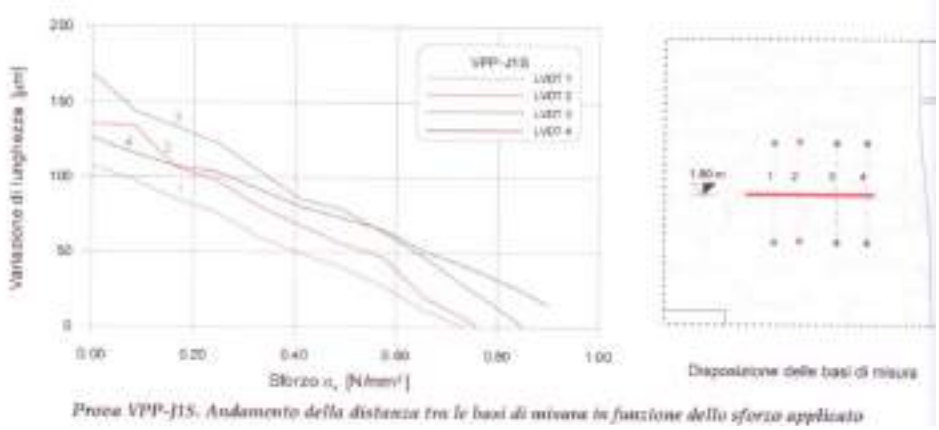
Fig. 4. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 45.

CLASS II: MECHANICAL ANALYSIS
TYPE 2: IN SITU FLAT-JACK LOAD TEST

DESCRIPTION

The load test with flat jacks has the purpose of determining the tensile state of the walls and their elastic modulus. It is of the non-destructive type – with the exception of irregular walls – since the cut is performed in mortar applications and the jack can be easily removed. The test instrumentation is simple and of relatively quick execution. If consolidation operations are carried out, it is also possible to use the jacks, previously installed, as pressure cells, leaving them connected to a pressure gauge, to detect any changes in voltage consequent to the work carried out, always taking into account the influence of temperature variations. By positioning a second jack orthogonal to the first one can determine the shear strength of the masonry, a parameter of considerable importance in seismic areas.

Fig. 5. Reading of the vertical movements with the flat jack inserted in the masonry wall. Hydraulic system connected to the flat jack inserted in the masonry wall. From F. Doglioni, G. Mirabella Roberti, *Venezia. Forme della costruzione, forme del dissesto*, Libreria Cluva Editrice, Venezia 2011, p. 208.



Prova VPP-J1S. Andamento della distanza tra le basi di misura in funzione dello sforzo applicato

Prova VPP-J1S	
Base di riferimento	SFORZO (N/mm²)
Base 1	0.74
Base 2	0.78
Base 3	0.85
Base 4	-
Stato di sforzo medio	0.79

Sforzo corrispondente all'annullamento delle variazioni di lunghezza tra le coppie basi (valori interpolati)

Fig. 6. Single flat jack test results (PP.MM. Laboratory, Politecnico di Milano, prof. L. Binda). From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 208.

EXECUTION

a) Identification of the most representative areas, favouring the lower parts, more loaded, and avoiding wads of doors or windows.

b) Positioning of three pairs of measurement bases and initial reading δO.

c) Execution of a horizontal cut in the normal direction to the surface and of two lateral cuts to allow free transversal expansion; reading δ1 < δO.

d) Insertion of the jack, connection to a hydraulic circuit, gradual increase in pressure; readings at each load level until it returns to the value δO, this load corresponds to the existing original stress.

e) Increase of the load up to the formation of the first lesions, indicative of the breakage of the masonry, and construction of the load movements chart.

f) Determination of the deformability characteristics by means of further deformometric bases in the masonry portion not disturbed by the cut.

Fig. 7. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 48.

a) Compressive strength test of masonry wall with flat jacks and size of jack.

b) Compartments in the masonry for the two jacks and deformation meter.

c) Extension of the contact surface between jack and masonry wall.

d) Loading-Deformation diagram.

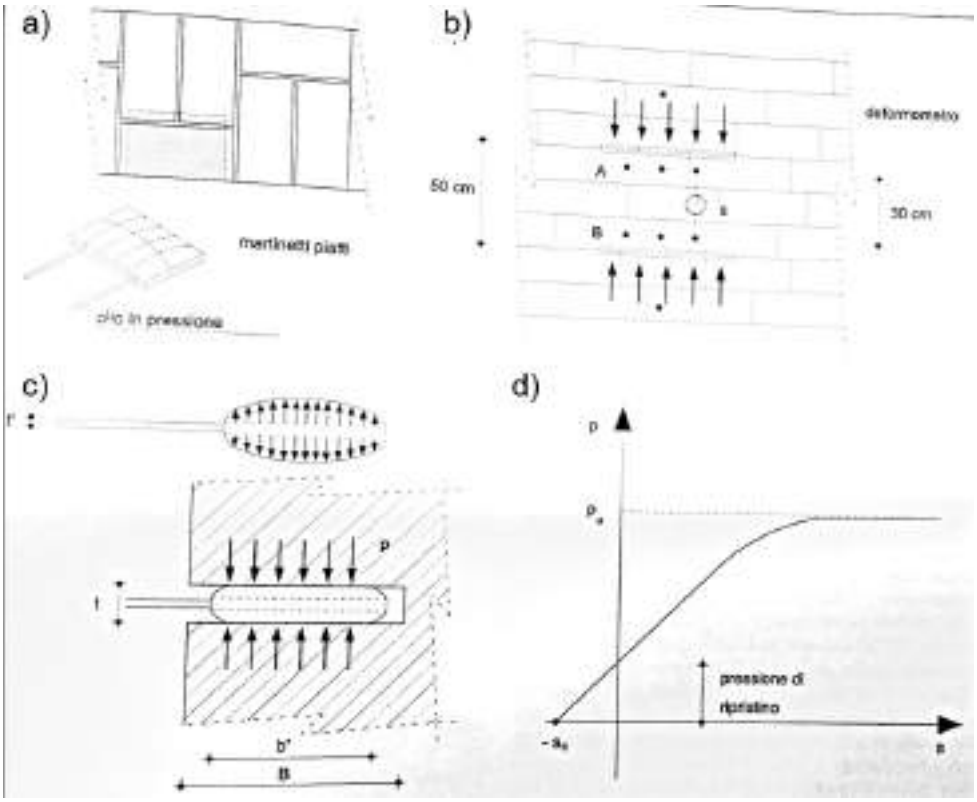


Fig. 8. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 83.

CLASS II: MECHANICAL ANALYSIS
TYPE 3: IN SITU BAR EXTRACTION TEST

DESCRIPTION

The in situ slip test allows for the detection of the limit tangential stresses present in the masonry to be examined. It consists in the tensile stress of a steel bar, previously inserted and anchored in the wall, by means of a jack, with the consequent extraction of a portion of masonry. By measuring the magnitude of the load until it breaks and detecting the surface of the extracted solid, the shear strength of the examined structure is evaluated.

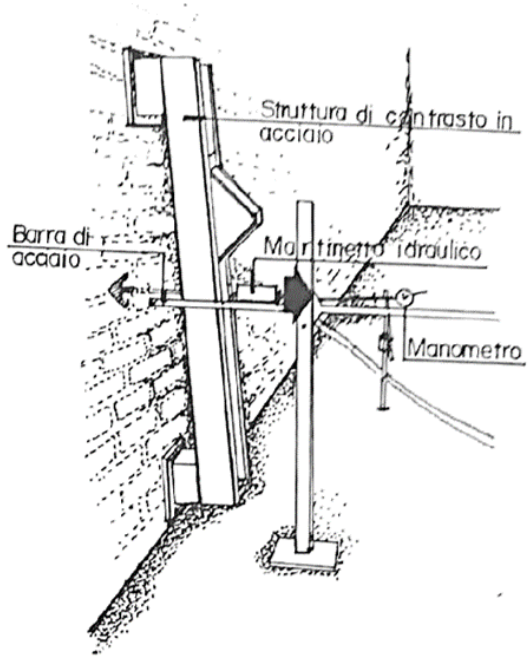


Fig. 9. Load application with hidraulic jack. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 51.

CHARACTERISTICS

This type of methodology allows us to define, together with the compression tests – in situ with flat jacks, in the laboratory on extracted samples – the "breaking domain" of the masonry. the proof allows for the direct verification of the values and is sometimes able to reconstruct very realistic conditions such as anchorages, chains.

EXECUTION

Insertion and anchoring of a steel bar in the wall to be examined.
Applying a steel contrast structure and applying a pulling force by means of a hydraulic jack, driven by a pump, to the steel bar previously inserted.
Measurement of the applied load gradually, until it breaks, by means of a precision manometer inserted in the hydraulic circuit.
Relief of the extracted solid, of conical shape, and determination of the limit tangential tensions.

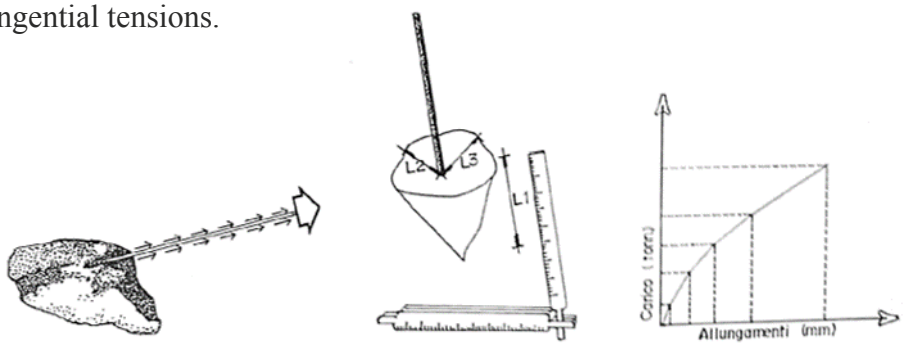


Fig. 10. Load application with hidraulic jack. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 51.

CLASS II: MECHANICAL ANALYSIS
TYPE 4: SAMPLE EXTRACTION FOR LABORATORY TEXT

DESCRIPTION

The execution of direct tests on samples taken on site is of great help in the quantitative evaluation of the mechanical, deformability and resistance characteristics, and of the chemical and physical characteristics of the examined models. It is important to pay attention in extracting the samples and for these to have sufficient dimensions to be sufficiently representative of the behavior of the masonry. The extraction of the specimen must be carried out using suitable instruments so as not to disturb the static equilibrium of the masonry and of the sample itself until its arrival in the laboratory. Once the core removal operation has been completed, the missing portion of masonry will have to be rebuilt, restoring the continuity of the wall with stone elements or bricks similar to those existing with mortar.

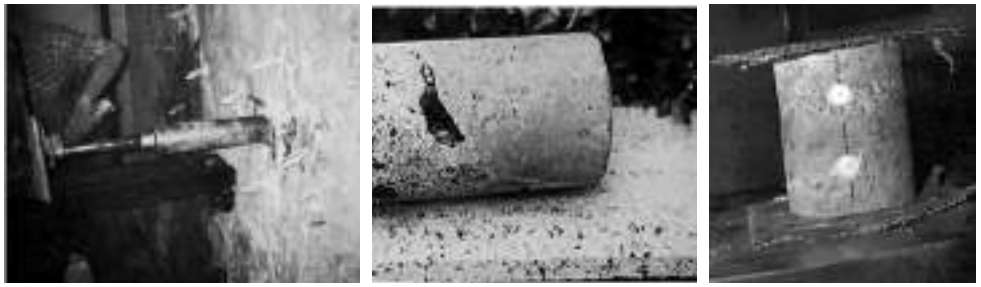


Fig. 11. 1. Sample extraction with rotating tube; 2. Extracted sample; 3. Mono-axial stress test. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 51.

EXECUTION

a) Identification of the most representative areas and extraction of the sample.

b) Conduction of the extracted specimen in the laboratory in order to submit it to:

b1) monoaxial compression test; longitudinal stress; determination of the breaking load and the deformation diagram;

b2) direct cutting test; loading the specimen and its stress in the normal direction increasing the load up to determine the sliding of the upper part with respect to the lower part to define the horizontal displacements according to the constant vertical load;

b3) direct traction test; application of a monoaxial tensile stress to obtain the breaking load;

b4) indirect tensile test; stress, compression in a horizontal direction along two opposed generators and, indirectly, tensile.

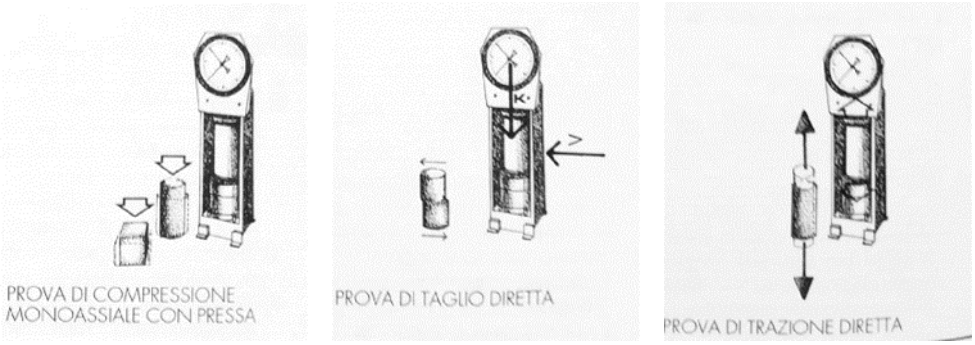


Fig. 12. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 46.

CLASS III: QUANTITATIVE ANALYSIS
TYPE 5: THERMOGRAPHY

DESCRIPTION

The thermographic analysis allows for quick and non-invasive detection of a series of data on structural and construction elements hidden by the presence of plaster. In particular, it makes it possible to identify the presence of: load-bearing structures, reinforced concrete elements, hidden stone elements, flues, voids, infills, tears, detachments, fractures, humidity, etc. The plaster is affected by the differences in temperature between the different materials underlying it and returns them, though attenuating them, to the external surface.

Thermography is essentially based on the ability of a material to retain or transmit heat. Through the detection of the thermal radiation emitted by the hot irradiated bodies it is possible to obtain, through thermographic images, video or photographic, a representative mapping of the materials present.

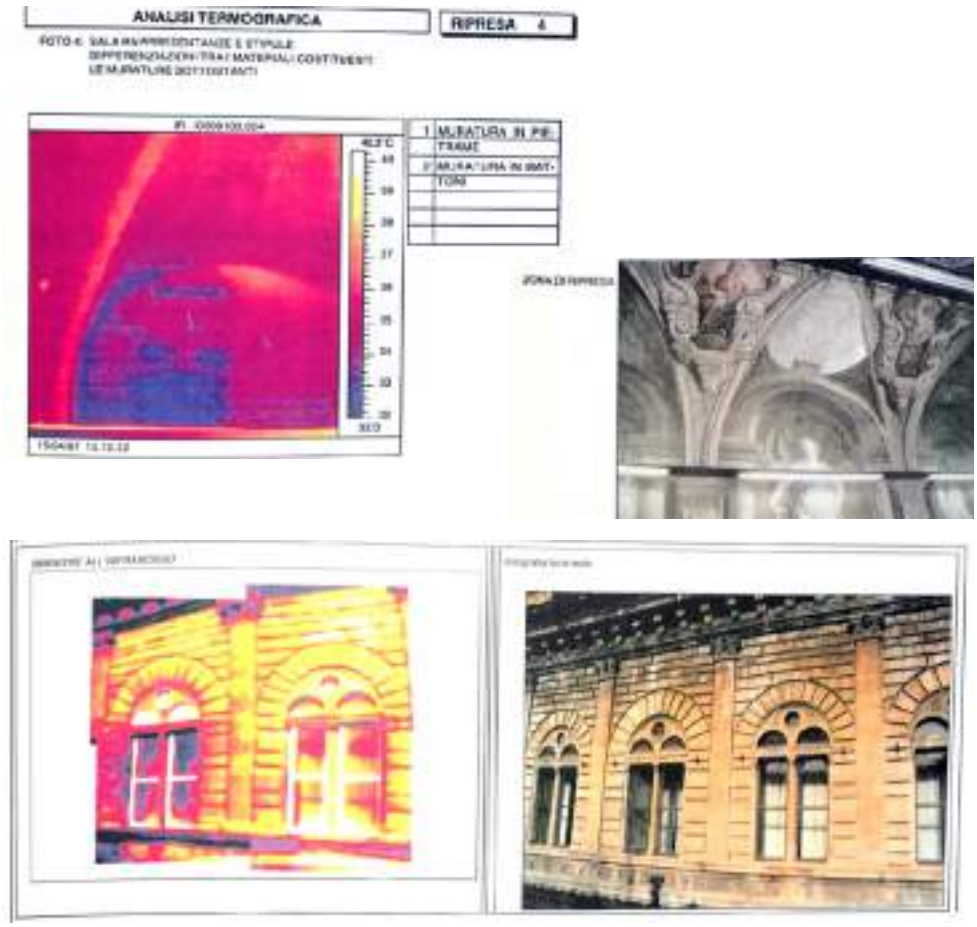


Fig. 13. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 55.

EXECUTION

a) Analysis of the camera-framed surface and transmission of the signal detected to a control unit. It varies according to the infrared radiation emitted by each individual point.
b) The field framed by the objective is divided into lines and focused points with very close intervals by means of a scanning system with rotating optical prisms; each element of the image is associated with an integer that varies from 0 (black) to 255 (white) according to the shade of grey.
c) Formation of an image in different shades of grey where the lighter areas correspond to the points of greatest radiance and therefore of greater temperature.
d) Recording of the digitized images on magnetic tape or photographic printing of the same directly from the monitor.

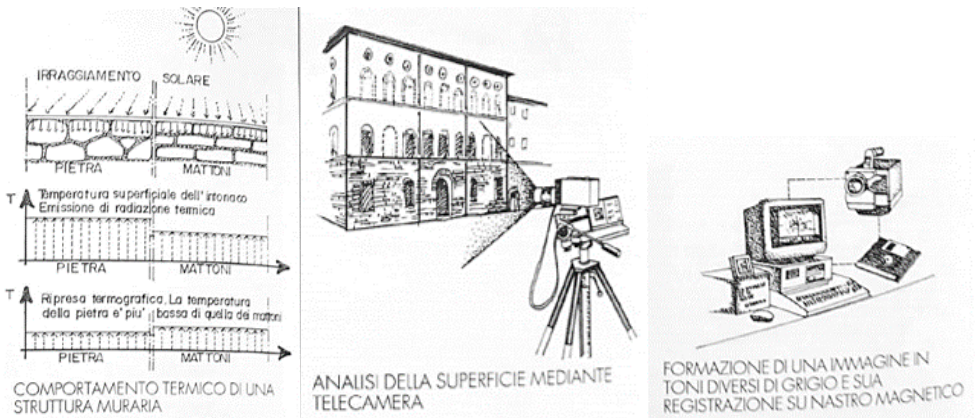


Fig. 14. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 52.

Fig. 15. Thermographic diagnostic. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 54.

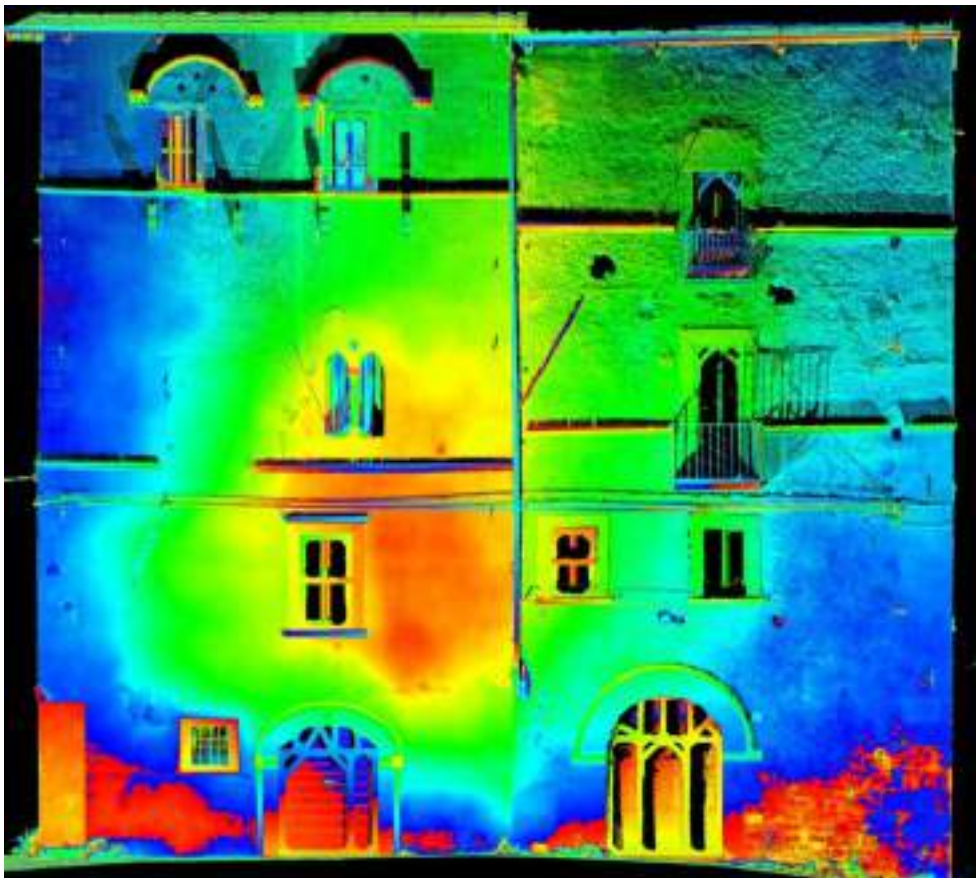


Fig. 16. Thermographic camera images. From F. Doglioni, G. Mirabella, *Venezia. Forme della costruzione, forme del dissesto*, Libreria Cluva Editrice, Venezia 2011.

CLASS III: QUANTITATIVE ANALYSIS
TYPE 6: SONIC TEST

DESCRIPTION

The dynamic auscultation method of a material allows us to determine, in an absolutely non-destructive way and with a good level of precision, the quality as well as the heterogeneity of the medium, be it stone, brick, lumber or concrete. The sonic tests consist in direct measurement of the propagation speed of the sound waves through an element and on the examination of the received signal. The more the material is compact and homogeneous, the greater the propagation speed of the sound impulses, since it does not find any attenuation or interference along its path, deriving from the presence of voids or discontinuities. Sonic investigations basically allow us to verify the distribution of the state of degradation – usually unevenly variable in historical walls – as a completion to the remaining static surveys.

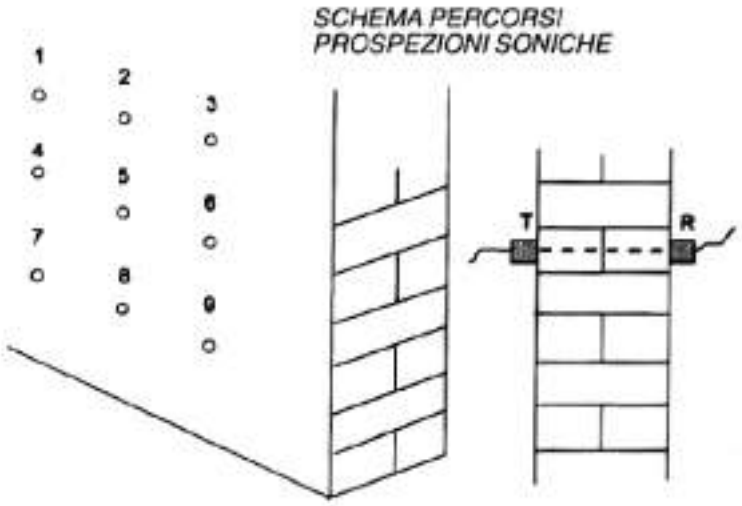


Fig. 17. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 57.

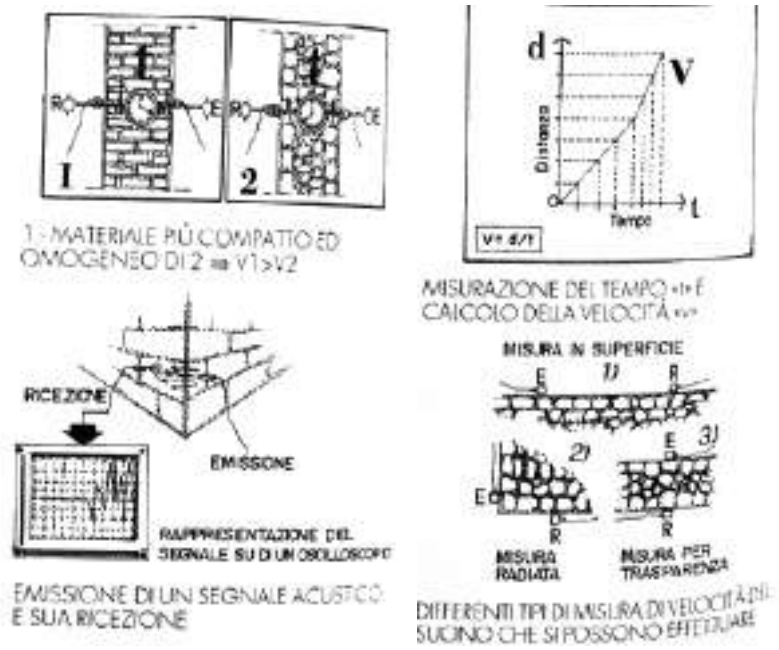
EXECUTION

a) Start of the measurement of time by sending a synchronized acoustic signal emitted by a transmitter placed in contact with the masonry portion to be examined and recording the arrival of the sound wave through a receiver, this in turn sends the signal to the receiver. measuring device that represents it on an oscilloscope.

b) Measurement of the time "t" between the emission and reception and analysis of the following parameters: frequency, amplitude, damping, reflection.

c) Note the distance "d", path of the acoustic signal, the velocity "V" (V = d/t) is directly proportional to the mechanical qualities of the material.

d) It is possible to carry out three different types of measurements according to the location of the two transducers: on the surface on the same face; radiated on two adjacent faces; for transparency on two opposite sides.



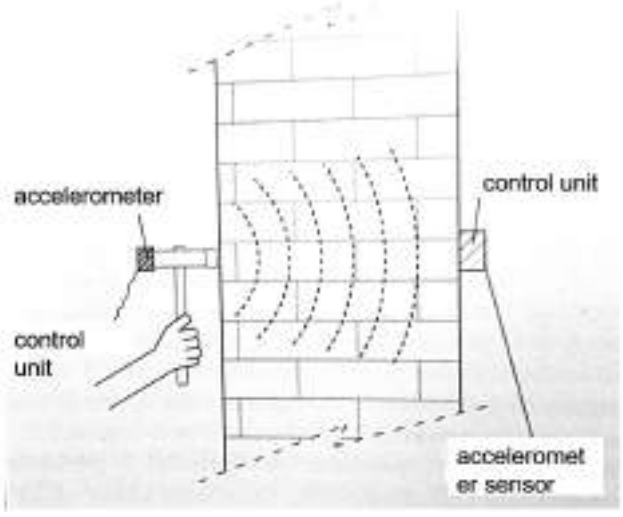


Fig. 18. Text execution. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 56.

CLASS III: QUANTITATIVE ANALYSIS
TYPE 7: SCLEROMETRIC TEST

DESCRIPTION

The sclerometric tests fall into the category of non-destructive tests to be carried out on site for the historical walls, not requiring the extraction of any sample. They consist in the detection of an indirect quantity by means of a special instrument, the sclerometer, defined by the rebound of a hurled flying mass, through a suitable mechanism, on the wall under examination. The parameter thus obtained, the surface hardness of the material, allows for the determination of the maximum breaking strength by compression of the investigated structure.

Fig. 19. Sclerometric test. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999.

EXECUTION

a) Removal of the plaster for a wall portion such as to perform from 5 to 10 beats at increasing pressure on the sclerometer continuously with spring loading; the rod retransmits the reaction to the mass by means of a rebound, the greater the more hard and compact the examined surface is.

b) Reading of the value of the same rebound on the graduated scale from which, through a suitable diagram, according to the chosen stop angle, the corresponding value of the compressive strength is obtained.

c) Average between measures taken by discarding those having a dispersion higher than the average square deviation replacing them with new ones.

d) The instrument can be used both on vertical surfaces and on floors, ceilings, and inclined surfaces. Representing the rebound of gravity uses different curves depending on the different positions or angles.

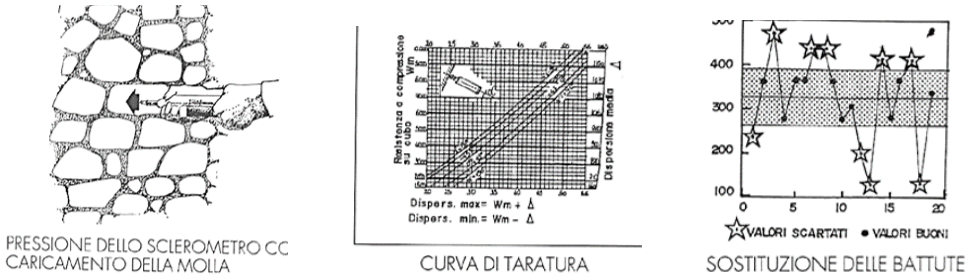


Fig. 20. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 59.

CLASS III: QUANTITATIVE ANALYSIS
TYPE 8: DYNAMIC TEST

DESCRIPTION

Non-destructive investigations conducted by means of dynamic tests are a valid tool for judging and controlling the conservation of the product. These aim to verify directly the stability of the building and to provide an overall evaluation of its dynamic characteristics according to different modalities: survey and analysis of the vibrational disturbances already present on the structure to be examined, of a continuative nature, such as road or rail traffic, or occasional, such as neighboring site activities, bell motions, wind, and low intensity forced vibration tests. Once the behavior of the building has been defined, it will be possible to calculate its structural response against dynamic actions having known characteristics, for example it will be possible to evaluate their real exposure to seismic risk.

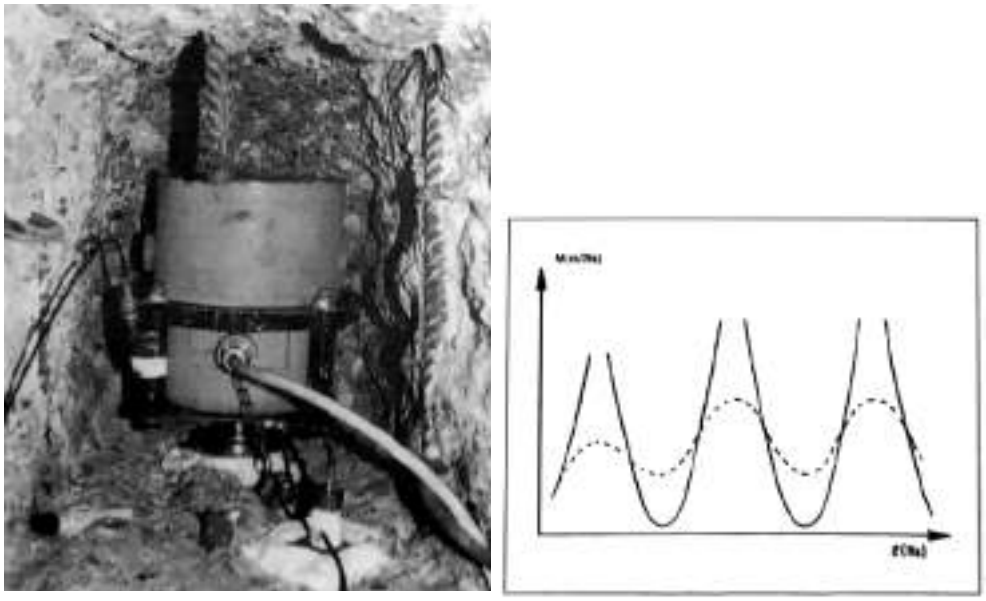


Fig. 21. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 61.

EXECUTION

a) Placement of seismometers at various altitudes located in the selected areas.

b) Possible recourse to an electrodynamic exciter:

b1) subjecting of the elements under analysis to forced dynamic excitation at low intensity, in order not to compromise the integrity of the structure;

b2) repetition of the excitation at regular intervals in two directions, parallel and normal, orthogonal to the plane of arrangement of the investigated structure.

c) Determination of modal parameters, frequencies, modal forms and damping, by means of the measured values and calculation of the dynamic response, in terms of displacements, velocities and accelerations, to the reference spectrum.

d) Interpretation of the response and evaluation of the structural integrity of the complex; possible realization of a finite element model, with proper distribution of masses and constraints.

Fig. 22. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 60.

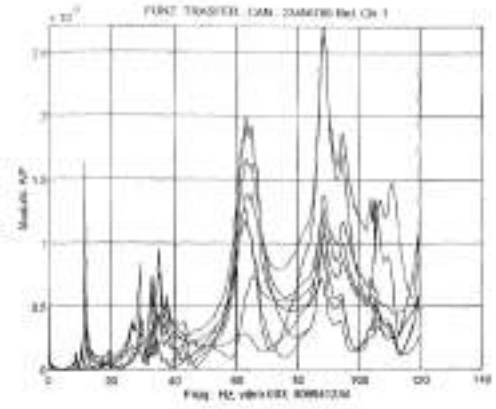


Fig. 23. Curves related to the resonance of a seismometer. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 61.

CLASS IV: INSTABILITY VERIFICATION
TYPE 9: HORIZONTALITY VERIFICATION

DESCRIPTION

A structure is subject in time to changes in its structure induced by static or dynamic phenomena. The former can also be controlled with intervals spaced over time, the latter require continuous measurements. In order to identify altimetric displacements, lowerings or elevations, we perform horizontality checks through the use of optical instruments, levels, and in some special cases, where it is not possible to perform horizontal readings, using tacheometers or theodolites.

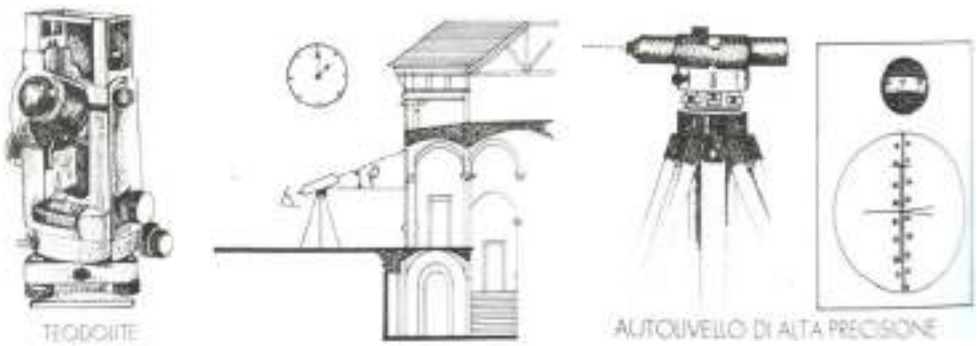


Fig. 24. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 62.

EXECUTION

The horizontality checks can be carried out by:
a) Optical precision measurements carried out with level:

a1) affixing a series of measurement bases, and detecting, at predetermined time intervals, the quotas relative to each base through mobile invariant stages; or by fixed stages if the checks are carried out in a monitored environment;

a2) ascertainment of vertical movements determined by the difference of two readings.

b) Optical measurements with a tilted view with instruments equipped with a vertical circle and distance graticule.

b1) Indirect assessment of vertical movements determined by trigonometrically known angle and inclined distance.

Fig. 25. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 62.

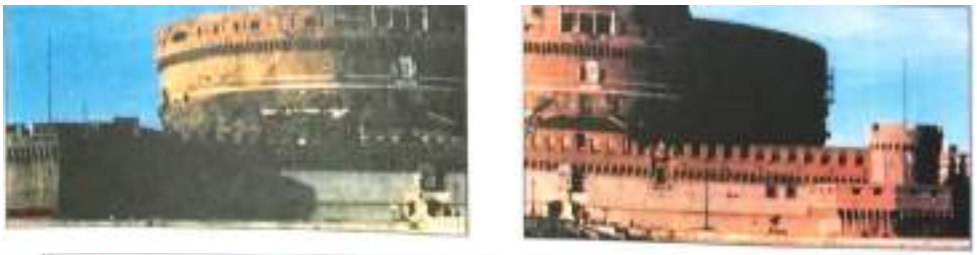


Fig. 26. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, pp. 62-63.

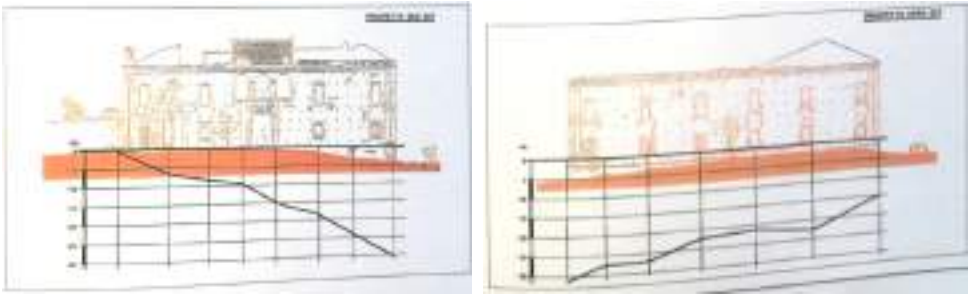


Fig. 27. Instability verification. Horizontality verification. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 63.

CLASS IV: INSTABILITY VERIFICATION
TYPE 10: VERTICALITY VERIFICATION

DESCRIPTION

The vertical controls make it possible to identify the displacements relative to the vertical of some points of the structure to be examined. Through the use of ordinary and rather simple methods such as: plumb line, electric slitter, inclinometer, tachometer, some movements of the structure can be detected: rotations, terminal failures, inflections outside of one's plane. With measures interspersed over time, for periods of typically not less than one year, seasonal variations can also be taken into account, and the evolutionary law of the movements detected can be determined.

Fig. 28. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 65.

EXECUTION

For the detection of vertical defects the following tools can be used: a) Plumb line: positioning of a wire, in a high area of the building, carrying a lead weight at its end. Measurement of the distance between the projection on the ground of the wire and the base of the product itself. b) Electric slitter: Inserting the plumb line in a container containing oil, which stops the oscillations, the lead is connected by means of a horizontal electric transducer to a switchboard which detects its displacements. c) Inclinometer: laying of a series of fixed instruments, positioned at different heights, which indicate their axis offset from the vertical to an automatic data acquisition system. d) Tacheometer: ascertaining horizontal movements determined trigonometrically by known angle and inclined distance.

Fig. 29. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 64.

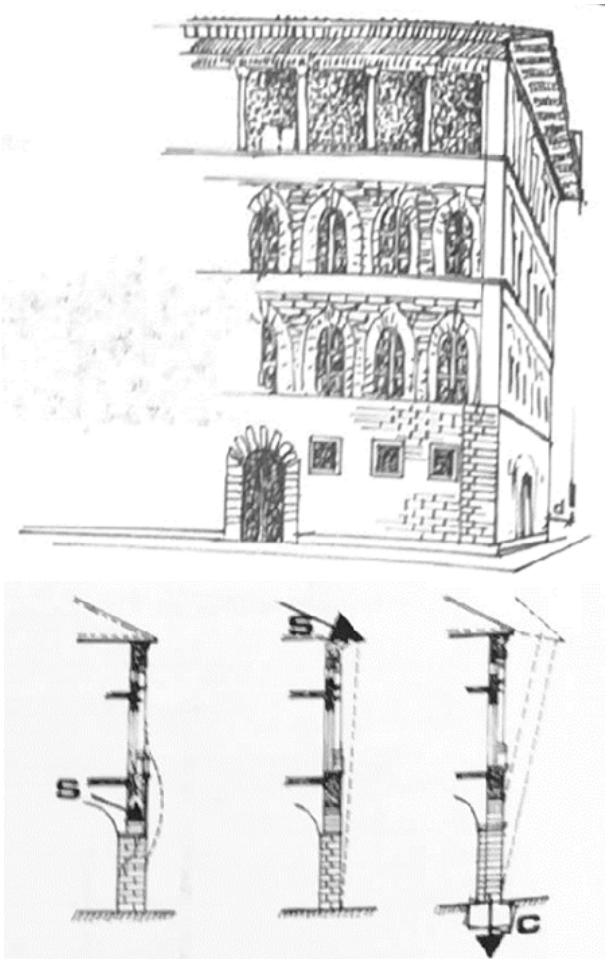


Fig. 30. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 64.

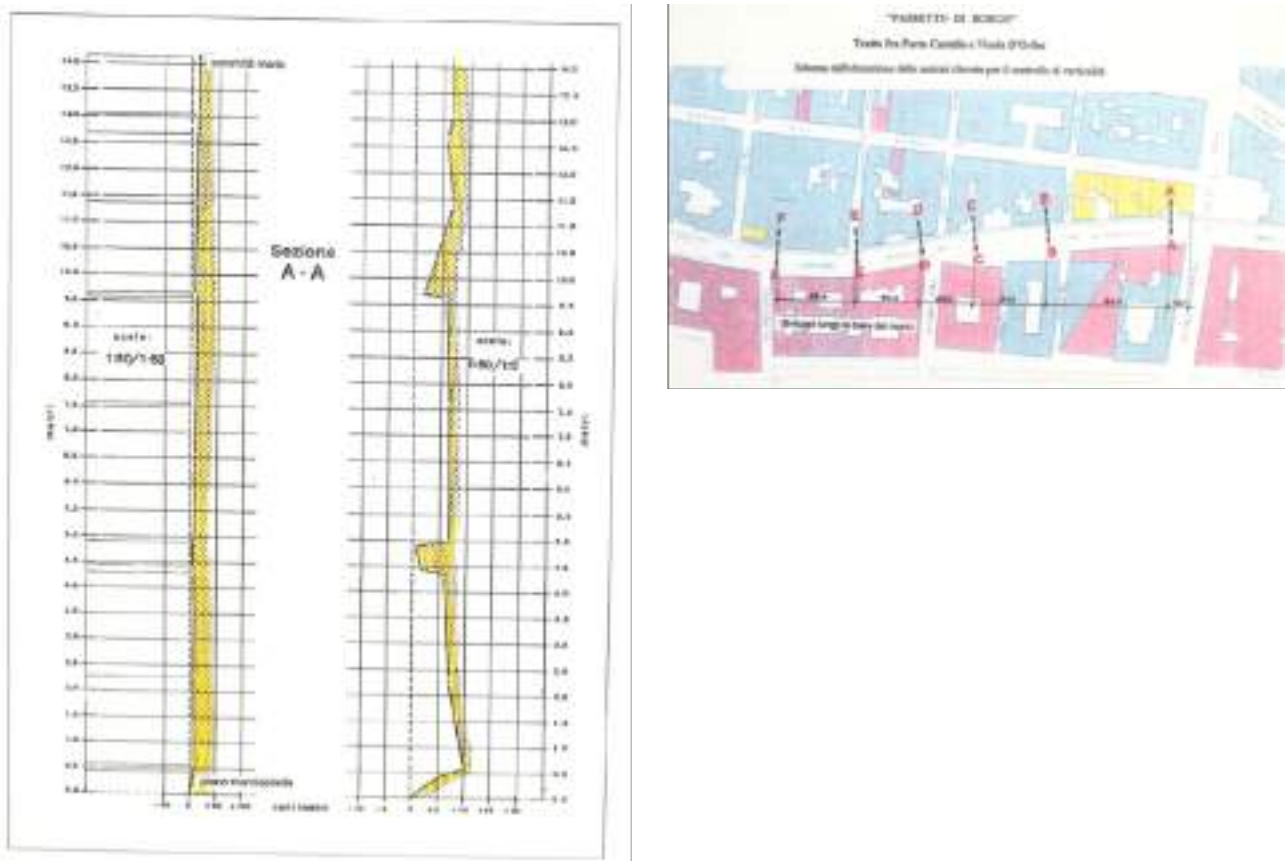


Fig. 31. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 66.

CLASS V: ELEMENTARY TESTS
TYPE 11: INJECTABILITY TEST

DESCRIPTION

The injectability tests allow a priori assessment of the preparation of the masonry towards the regeneration technique, that is the level of absorption of the mixture and the consequent effectiveness that is achieved. They also allow for the calibration of the input parameters by determining: pumping pressure and time, hole spacing, optimal proportion of the individual water components, binders, possible additives. The methods of execution are consequently variable according to the type of wall and its state of conservation. The described diagnostic method allows us to verify, through a comparison of the results obtained before and after the execution of the reclamation intervention, the effectiveness of the mixture injections performed.

EXECUTION

a) Execution of a series of small diameter perforations, having a depth equal to about 2/3 of the wall thickness, at predetermined distances by successive approximations.

b) Insertion in the prepared holes of tubes for the introduction of the mixture and their sealing. Subsequent wetting several times until saturation.

c) Pumping of the mixture into the masonry through the appropriate tubes.

d) Detection of the quantities absorbed according to the different pressures, interaxes, and the composition of the mixtures. Possible removal of masonry specimens, so as to be able to control the mechanical resistance in the laboratory.

e) Determination of the optimal dosages of the components of the mixture and of the injection methods for the execution of the wall regeneration intervention, in relation to the values obtained.

Fig. 32. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 67.

Fig. 33. Elementary tests. Injectability tests. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 68.

CLASS V: ELEMENTARY TESTS
TYPE 12: MAGNETOMETRY

DESCRIPTION

The magnetometry technique has the purpose of determining the presence of metallic elements hidden inside the walls, by means of a special detection instrument, without causing any damage to the integrity of the walls itself. The pachymeter, a transistorized portable device powered by a low-voltage battery, is used to conduct the test. Generally the described investigation is used to locate and identify the reinforcement in the context of non-destructive tests on concrete. The precision instrument is able to localize the depth of the reinforcement on site, or to determine its diameter. However, the investigation can be applied with good results to masonry buildings if you want to locate capes of metal rods hidden by the external covering, wall covering or plaster, or pipes, pipes, slabs, etc.

EXECUTION

a) Definition of the areas to be investigated, in which metallic elements are presumed to be hidden.

b) Positioning of the instrument against the structure to be examined and detection of the depth indicated by the index of the instrument calibrated in centimetres. The instrument locates and identifies reinforcements up to 200 mm deep.

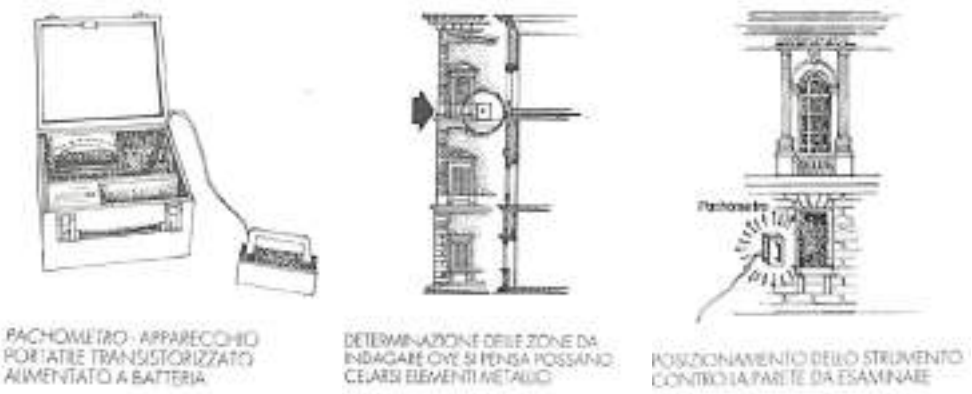
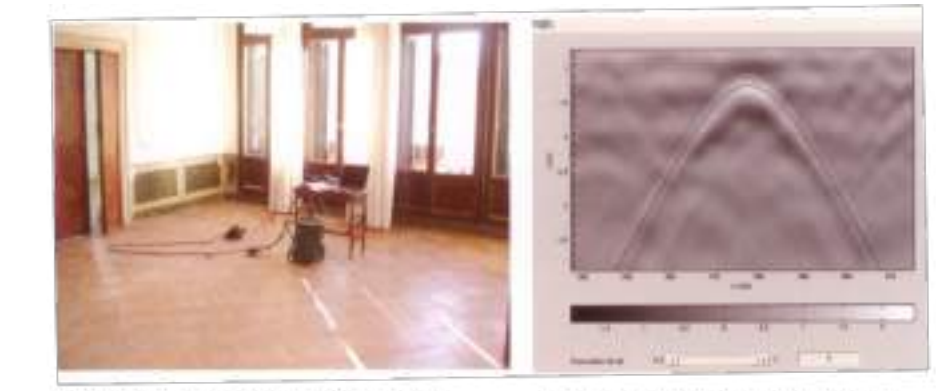


Fig. 34. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 69.

- Indagine geoRadar



Execution of surveys on the 2nd floor of Palazzo Pisani through GPR with 2 Ghz antenna with double polarity.

Elaboration of a radar trace: speed analysis conducted on the diffraction produced by a fluba.

Example of processed data in which 3 diffractions are observed. The vertex position identifies the distance and depth of the metal element that produced it.

Fig. 35. Elementary tests. Magnetometry. GeoRadar surveys at Palazzo Pisani in Venice (Italy) (PP.MM. Laboratory, Politecnico di Milano) From F. Doglioni, G. Mirabella Roberti, *Venezia. Forme della costruzione, forme del dissesto*, Libreria Cluva Editrice, Venezia 2011.

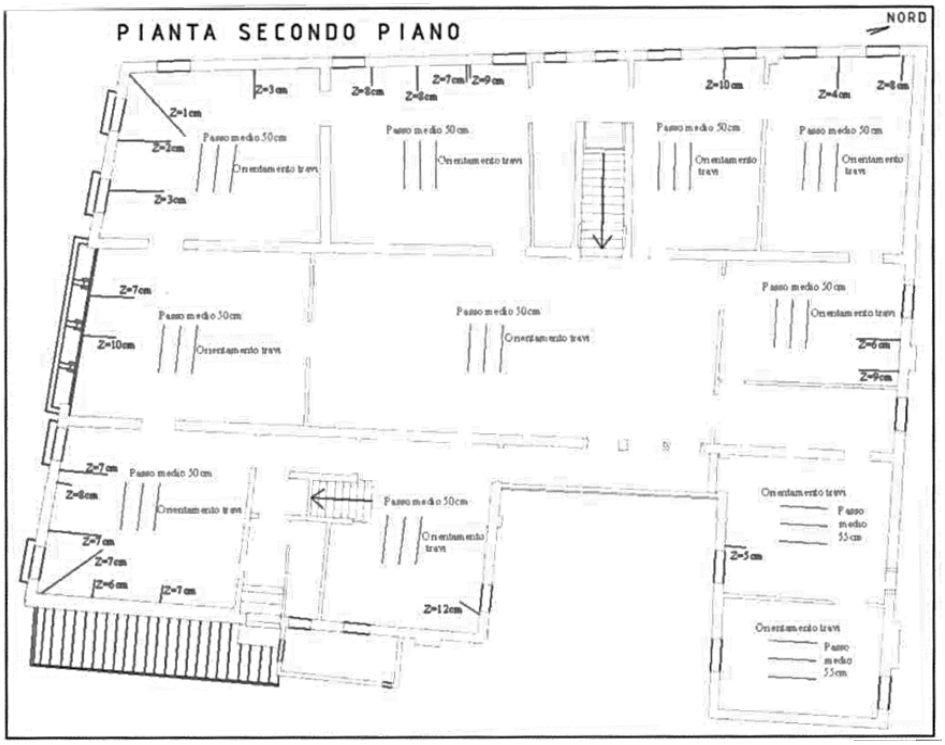


Fig. 36. GeoRadar surveys at Palazzo Pisani in Venice (Italy) (PP.MM. Laboratory, Politecnico di Milano) From F. Doglioni, G. Mirabella Roberti, *Venezia. Forme della costruzione, forme del dissesto*, Libreria Cluva Editrice, Venezia 2011, p. 211.

Location of the "fiube", not visible from the outside, and orientation of the beams of the second floor at Palazzo Pisani. The orientation consistent with that expected, which varies only in the north-east wing, can be observed.

CLASS V: ELEMENTARY TESTS
TYPE 13: ENDOSCOPIC TEST

DESCRIPTION

The tests consist of the direct visual examination within the building body in order to identify: construction types, morphological variations, discontinuities between the masonry walls, presence of internal cavities, detachments and lesions, efficiency of mortar joints and state of conservation of the same. The endoscopic examination allows us to evaluate the internal conformation of areas not reachable otherwise, carrying out an in-depth visual examination with the help of particular optical instruments employing two or more lenses. Generally, they use rigid endoscopes with a front view, consisting of a rigid metal casing provided at one end with a objective lens and at the other with an eyepiece, connected to a camera. The endoscopic investigation in the field of elementary tests is totally reliable, based essentially on the direct vision of the structure.

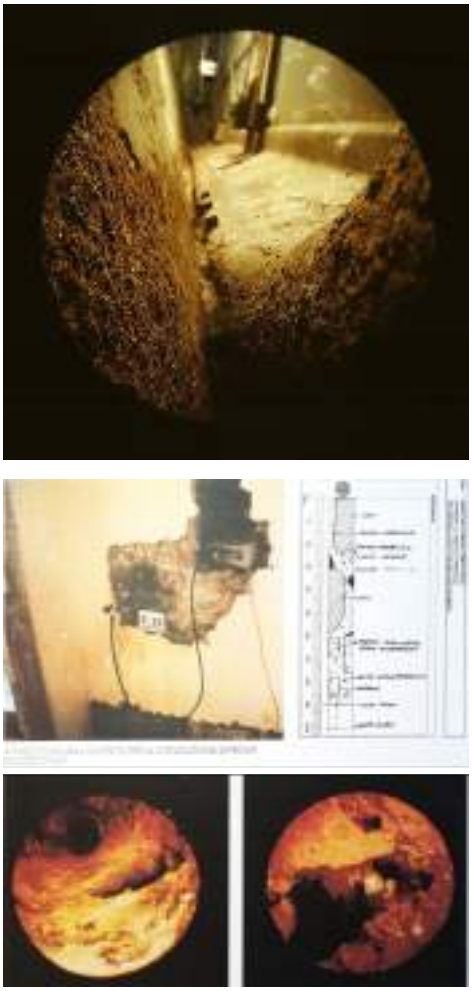


Fig. 37. Observation of non accesible areas by means of a camera. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 71.

EXECUTION

a) Execution of a passing inspection hole, having a diameter equal to 30-40 mm, by coring performed with rotary core with a diamond crown.

b) Insertion of a continuous metric reference inside the hole, whose beginning corresponds to one of the ends.

c) Inspection of the prepared hole, following the insertion of a rigid or flexible endoscopic probe connected to a light source with variable brightness, taking care to insert the probe coaxially and parallel to the hole itself.

d) Slow progress of the instrument in the thickness of the wall, noting what was detected during the test, and taking some shots in concomitance with the most significant situations.

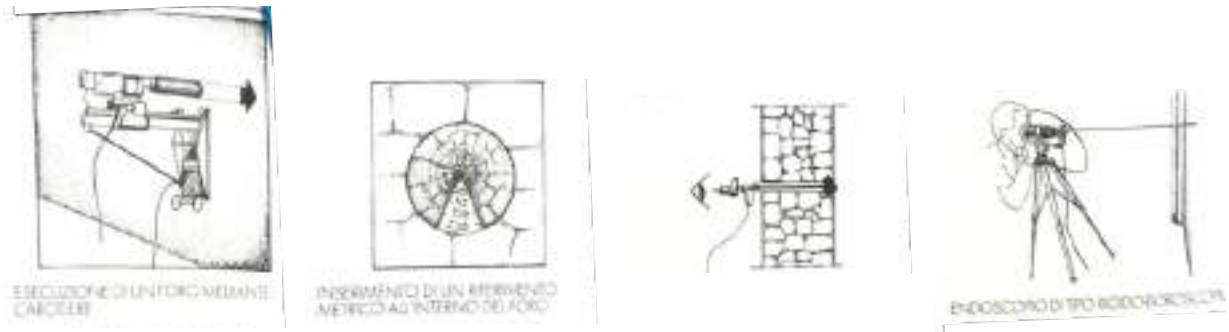


Fig. 38. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 70.

CLASS VI: PERIODIC ANALYSIS
TYPE 14: DEFORMATION MEASURE

DESCRIPTION

The methodology in question allows us to check the movements over time, cyclically measuring deformations or displacements relative to two close points. Since the lesions are the visible manifestation of the inadequacy of the structure to withstand the load conditions to which it is subjected, it is important to distinguish active fissures from inert ones. This will allow us to identify the critical areas in which to intervene after determining the characteristics of the relative movements. Measurements are made, after preparation of reading positions, by means of a deformometer, consisting of a casing in which two metal bars slide connected to a clockwork movement with a graduated quadrant. The bars have at their ends a point to be centered in the already installed bases, in the point-like markings prepared in them. The instrument has a high sensitivity, in the order of 1/100; 1/1000 mm.

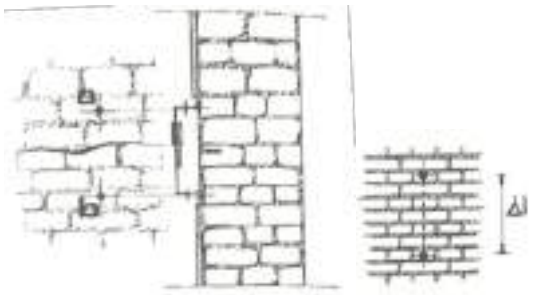
Fig. 39. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 73.

EXECUTION

a) Removal of the plaster.

b) Placement on the lesion of appropriate reading bases made of stainless steel, steel or brass, at a distance equal to the length of the reading instrument, by means of a spacer bar. A standard deformometer is about 10 inches (= 25 cm).

c) The measurements and the initial calibration on an invar basis are carried out by recording the measured values, and the thermal conditions of the product, at each inspection, usually by scanning them at regular time intervals.



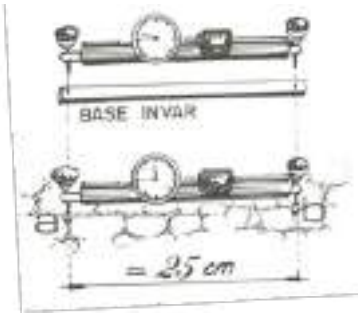
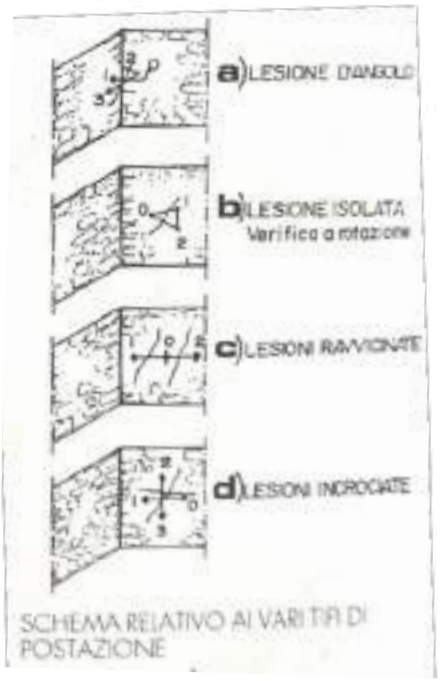


Fig. 40. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 72.



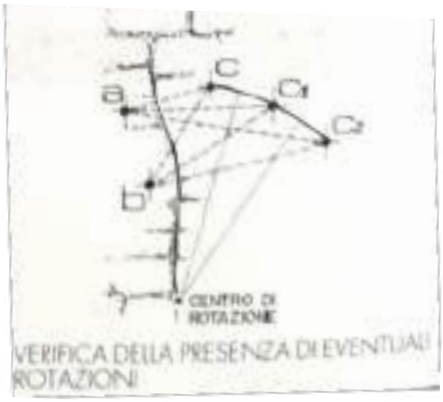


Fig. 41. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica,* Edizioni Kappa, Roma 1999, p. 72.

Fig. 42. San Bartolomé Parish Church. Susana Mora. Tarazona de la Mancha, Albacete 2000. (2)

Fig. 43. San Bartolomé Parish Church. Structural consolidation. Foundation reinforcement through micropiles. Sewed of factories. Follow-up through instrumentation. Susana Mora. Tarazona de la Mancha, Albacete 2000.

CLASS VI: PERIODIC ANALYSIS
TYPE 15: STRUCTURAL MONITORING

DESCRIPTION

The structural monitoring allows to control the evolution of the deformation process, or of the displacements, continuously in time, through the survey of the assembly movements of the structure and of the local alteration phenomena. The installed instrumentation network provides real-time information and is connected to a data acquisition unit and to alarm systems able to promptly report any anomalous situations; the purpose of the test is to get to know the structural behavior of the examined building as well as to check the evolutionary laws of previous failures, or still in progress, arriving at a timely assessment of risk levels. This will allow the consolidation work to be optimized from the point of view of minimal and targeted intervention while respecting the artistic and historical value of the work.

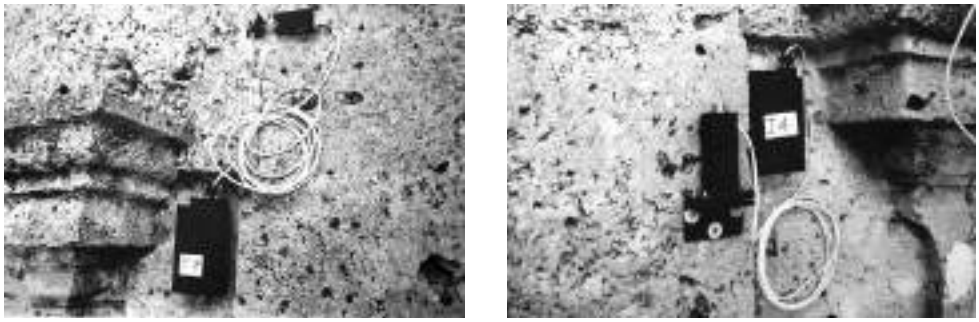


Fig. 44. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 75.

EXECUTION

a) Structural survey of the building to be examined and preliminary identification of critical points to be monitored.

b) Positioning of sensors, inductance transducers, at the identified points.

c) Connection of peripheral units, transducers, to the central data acquisition unit, referring to detection of: horizontal, vertical displacements, rotations and lesion variation, based on an intelligent system able to acquire analog signals and transform them into digital signals.

d) Transmission of data collected by the device by telephone, by modem, to the control station, and processing of data transmitted by electronic calculator.

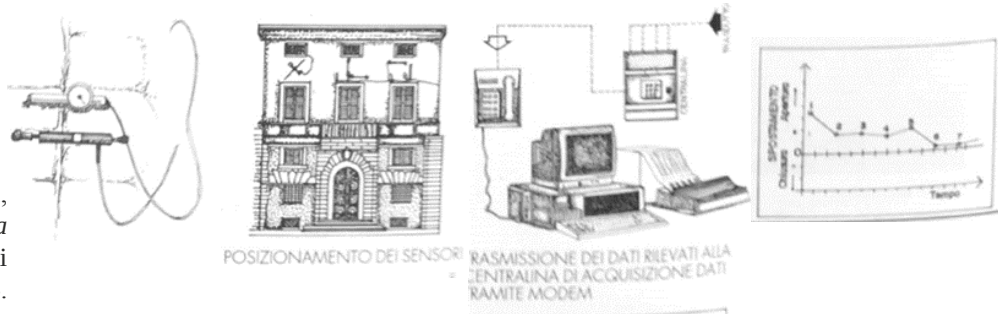


Fig. 45. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 74.

CLASS VII: HUMIDITY CONTENT ANALYSIS
TYPE 16: ELECTRIC RESISTENCE AND CAPACITY MEASURE

DESCRIPTION

Both methods measure the moisture content of a porous material. The method of resistive electrical measurements is based on the consideration that masonry can be assimilated to a resistance by applying two close probes the material connected to a reading instrument. The measuring devices provide the values, expressed as a percentage, of the water content. The electric current will be inversely proportional to the measurable resistance between the two fixed needles, and directly proportional to the amount of water present. The capacitive measurements consist in detecting the dielectric constant of a portion of plaster on which two plate electrodes are placed on the surface. The latter can both be located on the same wall, or on two sides of the structure; in the first case the measured constant is that of the contact material, in the second one of the entire section interposed between the two detection plates.

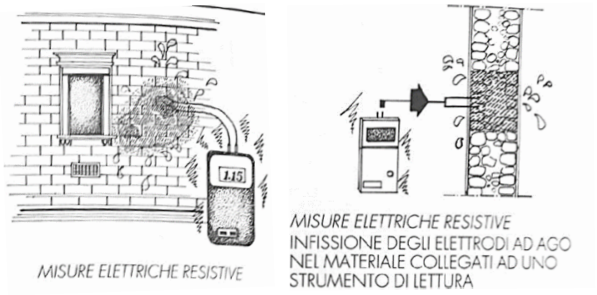


Fig. 46. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 76.

EXECUTION

a) Resistive electrical measurements: after preliminary calibration, inserting needle electrodes into the material. Sealing of holes and activation of current passage. Instrumental measurement through ohmmeters and comparison of the values measured with the initial calibration.

b) Capacitive electrical measurements: positioning of two plate electrodes on the portion to be investigated, determining the dielectric constant of the contact material, or of the entire section, in a dry area. Definition of the dielectric constant of the material, or of the entire section, humid. Even small amounts of water are detected through a substantial change in the dielectric constant; purification of results by comparison between the two measurements, in a dry and humid zone, and determination of the presence of moisture by subtraction.

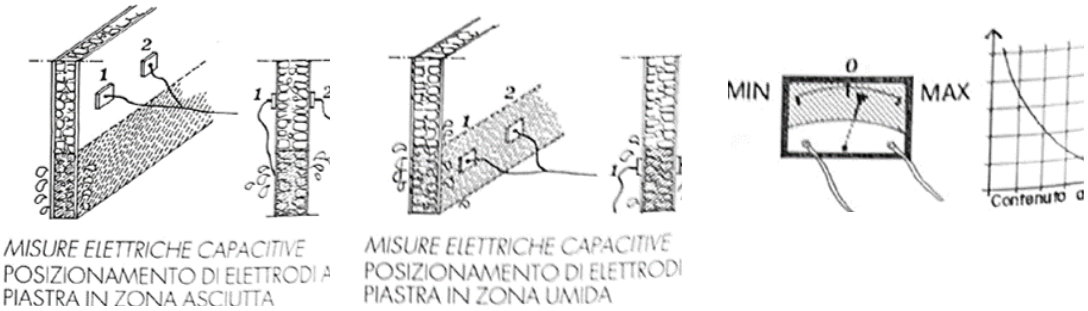


Fig. 47. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 76.

CLASS VII: HUMIDITY CONTENT ANALYSIS
TYPE 17: CALCIUM CARBIDE ANALYSIS

DESCRIPTION

This methodology has a greater reliability than that of electrical, resistive and capacitive measurements, if the composition of the examined material is known precisely, otherwise it is completely similar to them. The principle on which it is based is that of reading the pressure generated by a gas that is released as a result of a particular chemical reaction, in the presence of water. More precisely, by mixing a sample of damp masonry with calcium carbide (Ca C2), a gas, acetylene (C2 H2) develops, directly proportional to the amount of water contained in the specimen. When the chemical reaction occurs in a closed environment, the gas released exerts a pressure, the greater the quantity of gas, and therefore the water content; the stress measured by a manometer indicates the values relative to the humidity present in the material.

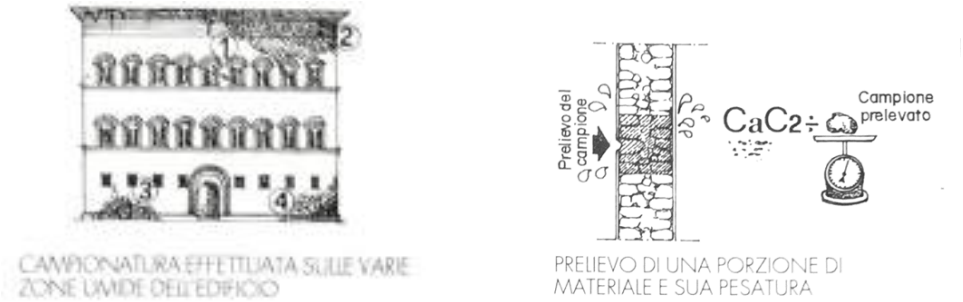


Fig. 48. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica,* Edizioni Kappa, Roma 1999, p. 77.

EXECUTION

a) Collection of a standard amount of material and its reduction to powder; predisposition of a predetermined dose of calcium carbide in proportion to the material taken.

b) Placing the two materials separately, in successive stages, inside a special non-deformable and hermetic metal container.

c) Closure of the container and its shaking.

d) Acetylene, which develops as a result of the chemical reaction between the calcium carbide and the water contained in the material, confined by the rigid wall of the container, exerts pressure on the manometer that closes the container.

e) The value of the detected pressure is a function of the water present in the masonry sample, and therefore indicates the values of the humidity present in the material referred to the dry weight.

Fig. 49. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica,* Edizioni Kappa, Roma 1999, p. 77.

CLASS VII: HUMIDITY CONTENT ANALYSIS
TYPE 18: PONDERING MEASURES

DESCRIPTION

The type of analysis described here, of rapid execution, based on a very simple principle, if carried out correctly, provides results of considerable precision, much better than those achievable with the methods described in the other entries of the same class 7. The test consists of taking a sample of masonry using a core drill, and weighing it when drawing and after having dried it; the difference between the two weights indicates the water content present in the sample. Usually, several samples are taken at the depths to be investigated. The execution of the assessment does not require the use of specific equipment, in fact it is sufficient to have a stove to dry the sample and a precision scale.

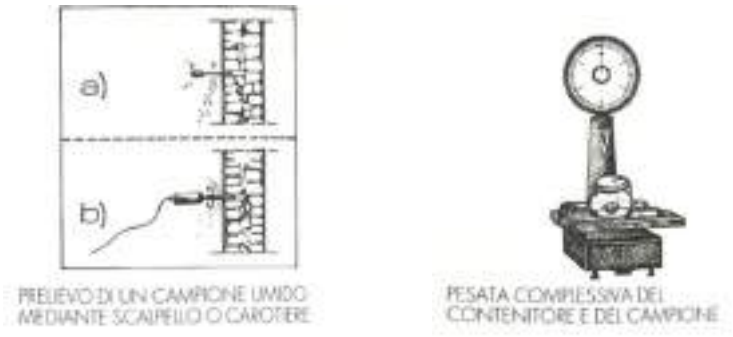


Fig. 50. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 78.

EXECUTION

a) Collection of a wet material sample by means of a chisel or core drill, at very low rotation speed (100/200 rpm), in order to avoid heat development with consequent evaporation of the water.

b) Insertion of the sample taken in a special glass container, or in polyethylene, previously weighed, with a sealed cap, and transported to the laboratory. Care should be taken not to expose the container containing the sample to temperature changes in order to ensure good preservation.

c) Execution of a total weigh, container and sample.

d) Additional weighing, this time only of the sample extracted.

e) Drying in an oven at a temperature of about 105 °C, up to constant weighing; determination of the weight of the dried sample and the percentage of relative humidity referred to wet weight, dry weight, and volume.

Fig. 51. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999, p. 78.

WOODEN CONSTRUCTIONS

(3) A. Geometrical, material and mechanical survey

B. Damage maps

C. Damage tests

A. GEOMETRICAL, MATERIAL AND MECHANICAL SURVEY

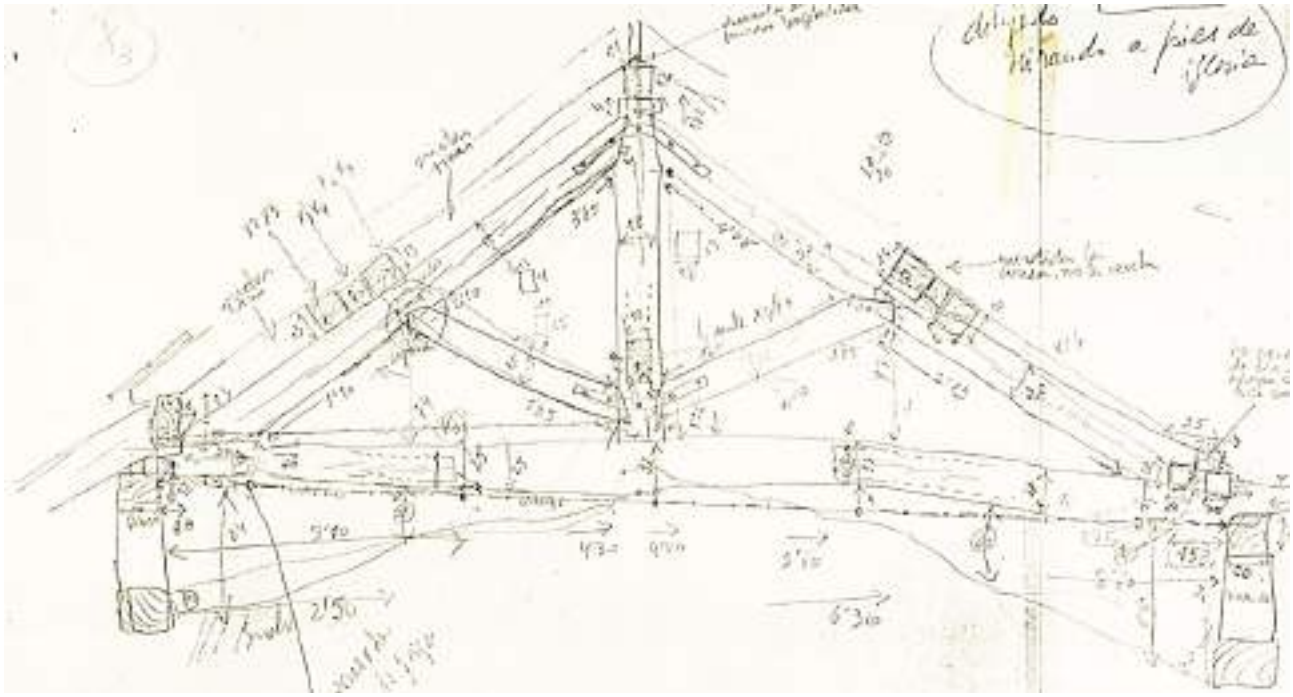


Fig. 52. Sketch of a wooden truss with measurements and constructive indications. Santa María de los Reyes, Grijalba, Burgos. Susana Mora. (4)

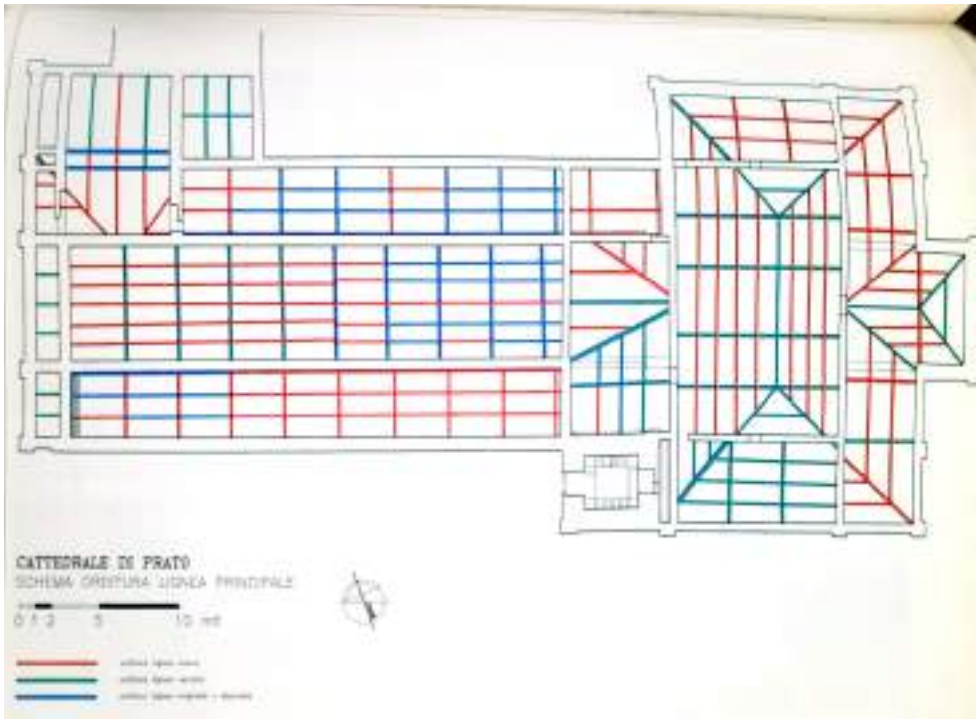


Fig. 53. Roof survey. From G. Carbonara, *Trattato di restauro architettonico*, vol. 4, Utet, Torino 1996, p. 303.

Constructive detail and material characterization

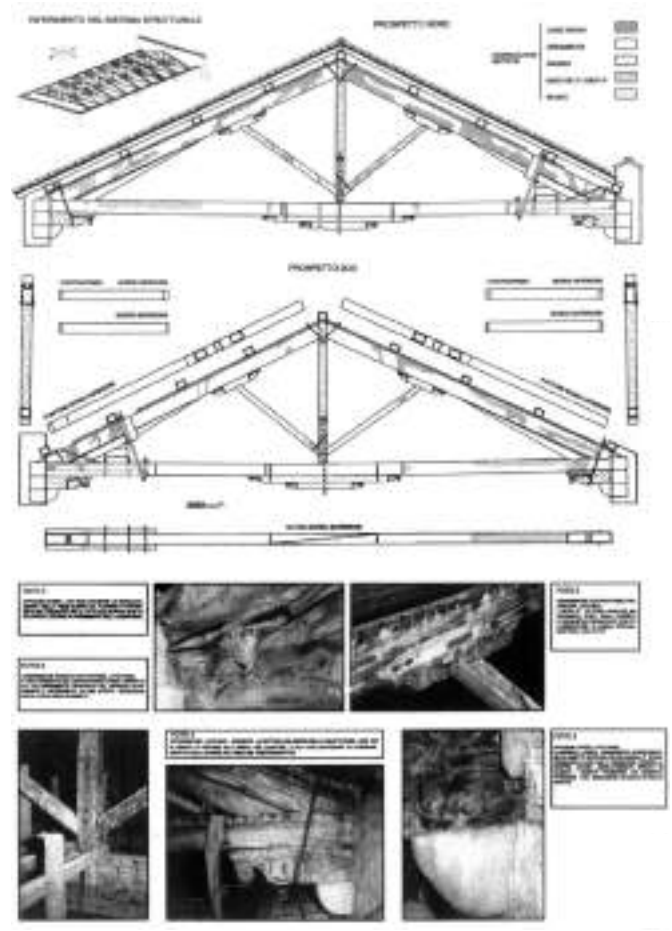


Fig. 55. From G. Tampone, *Conservation of Historic Wooden Structures*, Florence 22-27 february 2005, vol 1. Alter Ego Ing Arch, Firenze 2005, p. 156.

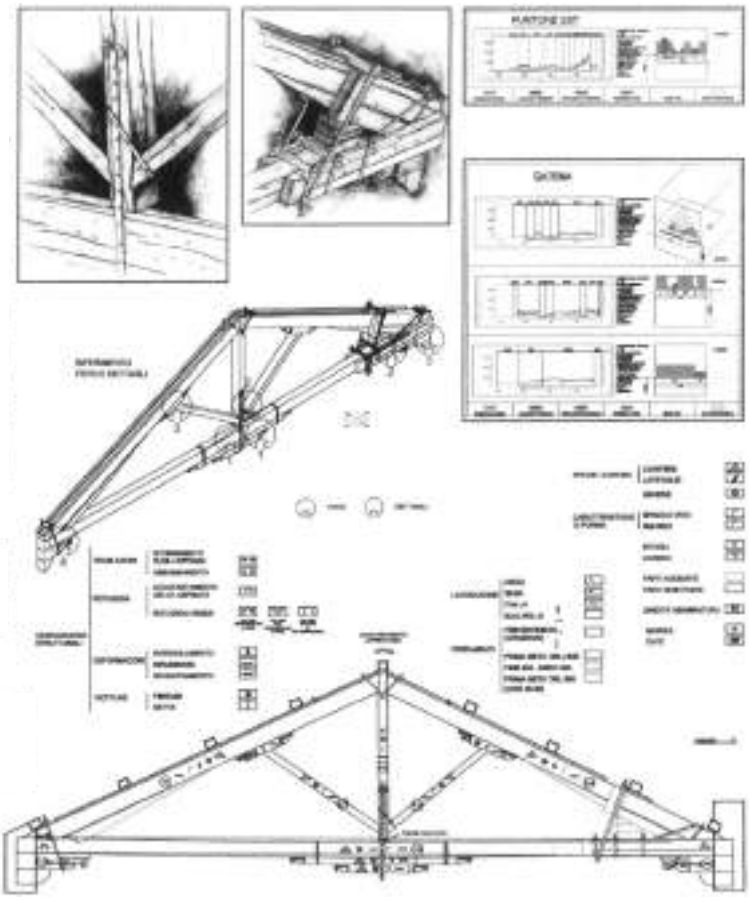


Fig. 55. From G. Tampone, *Conservation of Historic Wooden Structures*, Florence 22-27 february 2005, vol 1. Alter Ego Ing Arch, Firenze 2005, p. 156.

B. MAPS OF DAMAGE

Fig. 56. Analitical diagnosis data card including: list of damages, location and codification of test performed on the truss and typological recognition of wood species. Redesgined by Susana Mora.

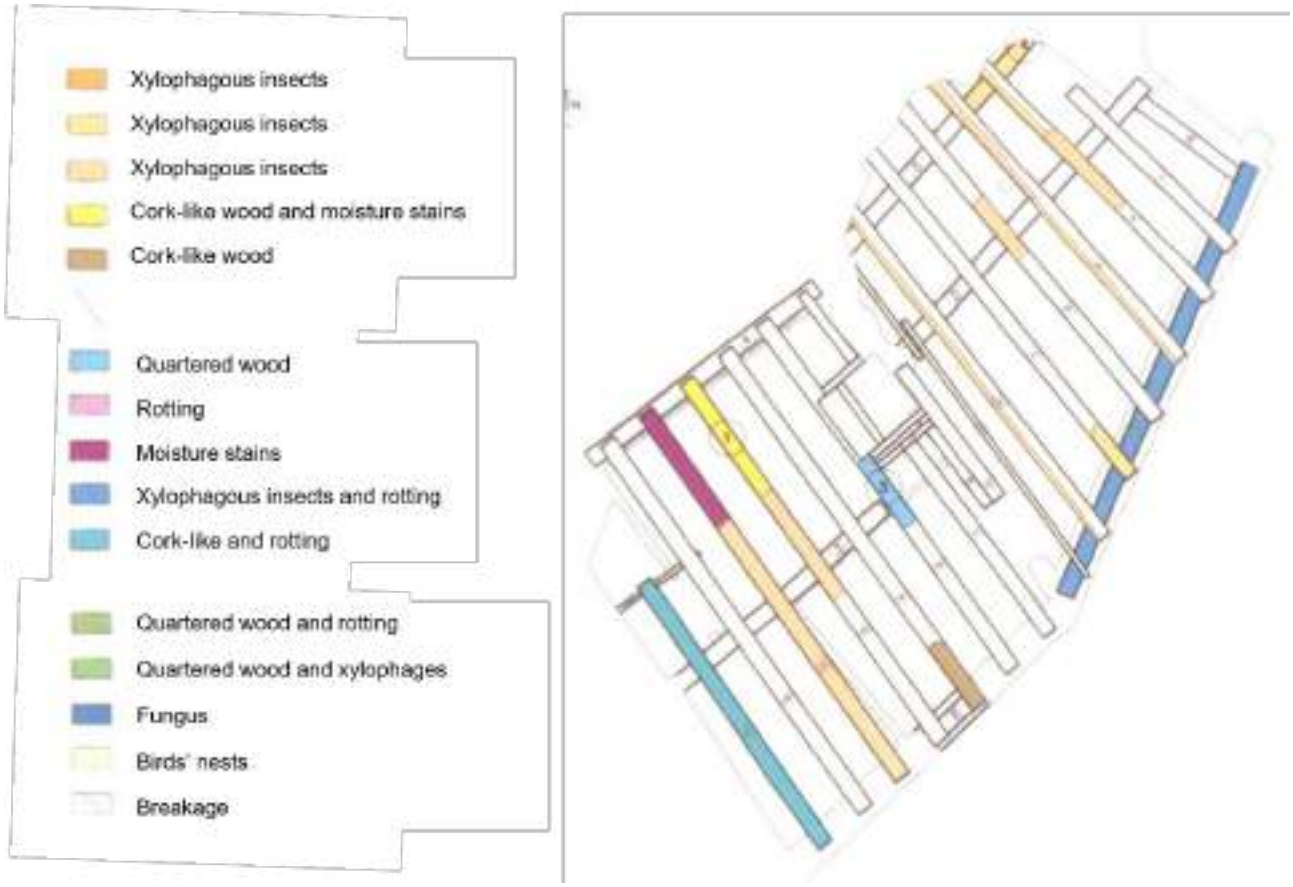


Fig. 57. Damages types identification. Redesigned by Susana Mora.

C. DAMAGE TESTS

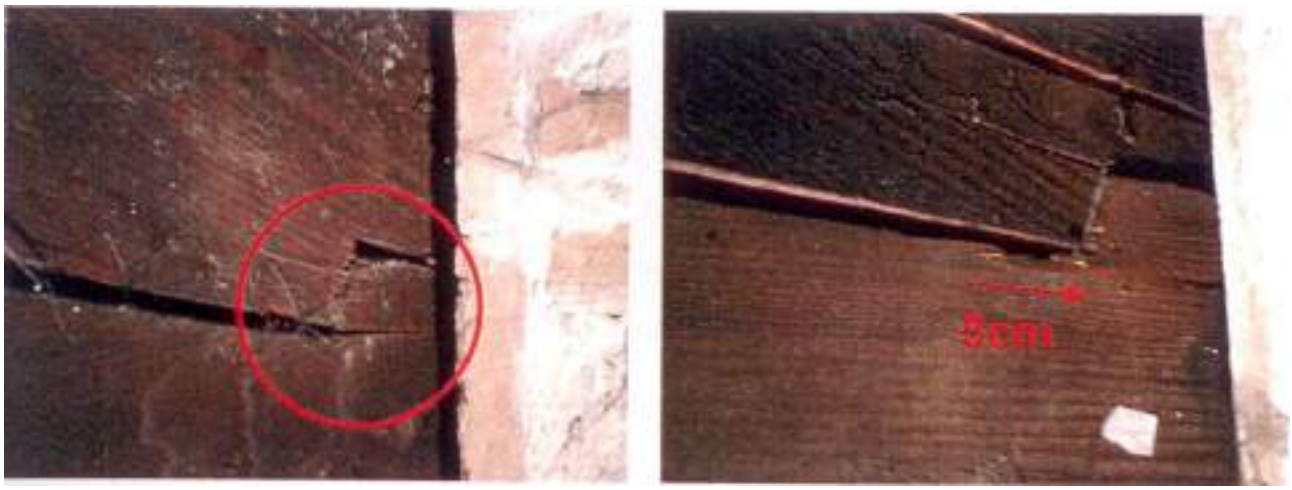


Fig. 58. Analysis of specific damages. Suffering of the cutting tooth (left). Breakage with relative sliding of the elements (right). From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999. (5)

Fig. 59. Analysis of specific damages. Attack of anabids xylophagous (left). Attack of cerambicides xylophagous (right). From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999.

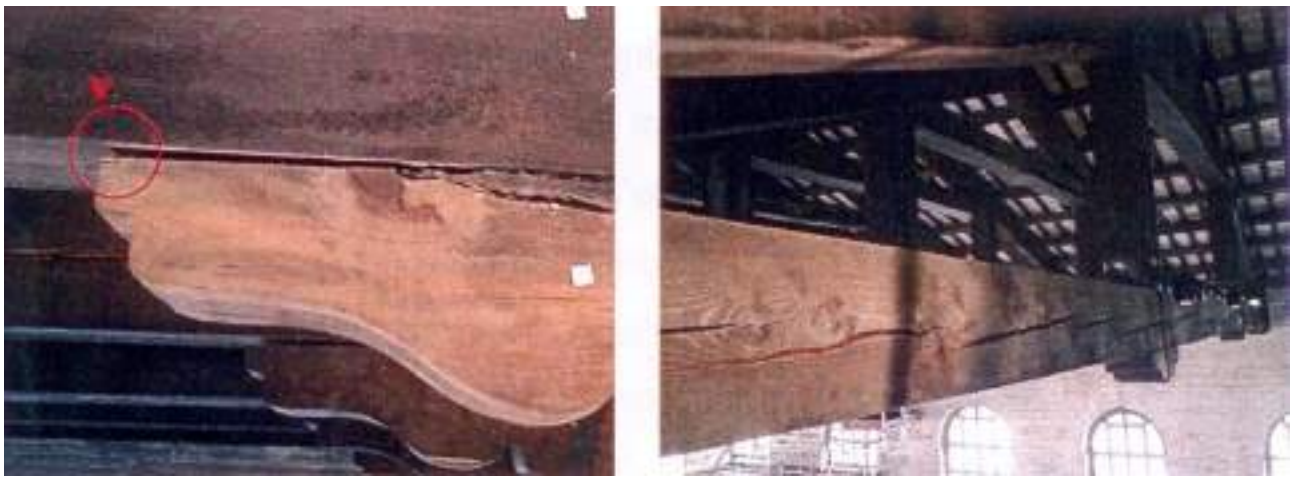


Fig. 60. Vertical deviation between bracket and tie-beam (left) and longitudinal fissures due to tie-beam shrinkage (right). From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999.

Fig. 61. Visual, photographical and geometrical survey. From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999.

Fig. 62a. Moisture survey (left) and example of the coding assigned to the truss head with indication of the execution points (right). From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999.

Fig. 62b. Perforations with resistograph in span (left) and in correspondence of the support (right). From P. Rocchi, C. Piccirilli, *Manuale della Diagnostica*, Edizioni Kappa, Roma 1999.

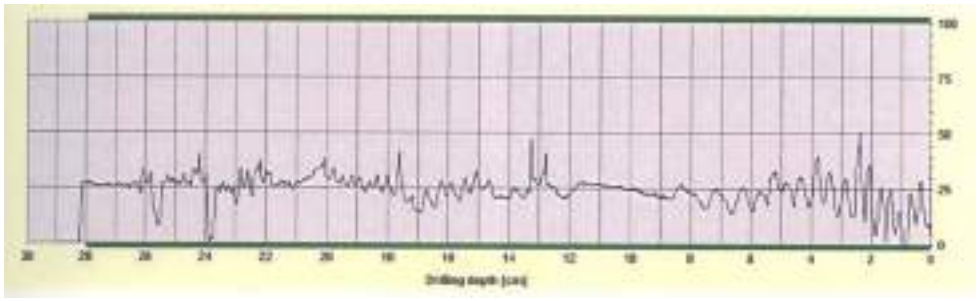


Fig. 63. Drilling depth-Resistance diagram for a «healthy» shelf.

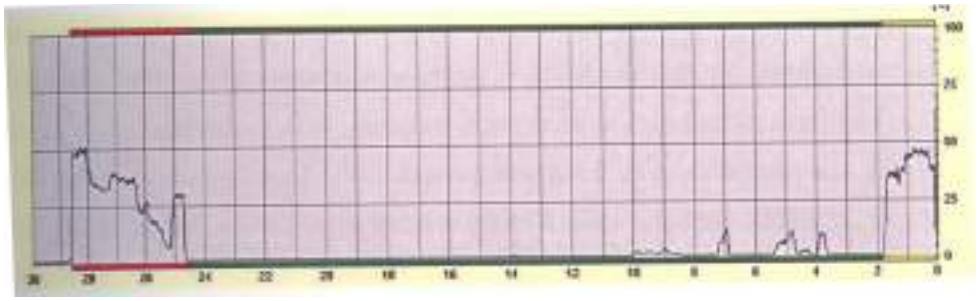
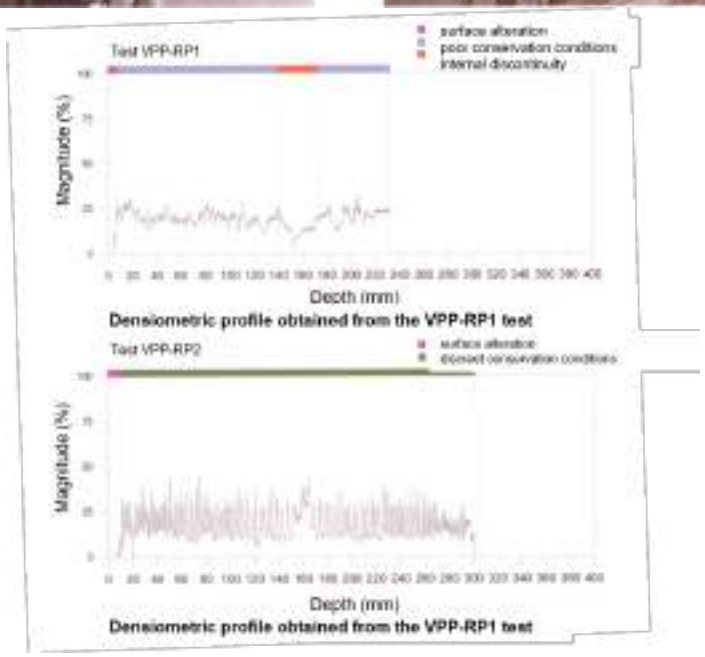


Fig. 64. Drilling depth-Resistance diagram for a degraded shelf.

Penetrometer tests on wood:

Fig. 65. Reading the humidity inside the beam. (Left). Performing the penetrometer test. (Right) (PP.MM. Laboratory, Politecnico di Milano). From F. Doglioni, G. Mirabella, *Venezia. Forme della costruzione, forme del dissesto*, Libreria Cluva Editrice, Venezia 2011.



NOTES

About general philosophy: Test for masonry and wood

On remembering the pioneristic study on wood, by Paolo MORA,

1) The study should seriously deal with the most varied problems attached to the life of the monuments and covers many fields (perharps unforeseen). Therefore a complete study should be provided, organized in a global and organic way and that can be adapted to the infinite number of monumental variations. In DE ANGELIS d'OSSAT G., *Guide to the methodical study of momuments and causes of their deterioration*, Roma 1972, p. 5;

2) Simple structural monitoring has being done by Susana Mora before, during and after the restoration of the church of San Bartolome in Tarazona de la Mancha, Albacete, Spain, directed by her as architect, for the "Junta de Comunidades de Castilla-La Mancha" (1995-The follow-up must be done during some periods of climate changes as from winter to spring and from summer to autumn);

3) On the conservation of wood, see the historical study by TAMPONE. G., *Il restauro delle strutture in Legno*, Milano 1996; to the numerous studies launched within ICCROM: by Paolo Mora e all'Istituto Centrale del Restauro. Untill the 19th century, wood was the only material that was resistant to both compression and to traction and that was readily available in structural sizes. The products that were available led to standardisation, with modular structures and prefabricated building parts, created according to a set constructive procedure related to structural typology. From TAMPONE G., *The slow progress of the conservation of wooden structures and wooden architecture, in Proceedings of the international conference Conservation of Historic Wooden Structures*, Florence 22-27 february 2005, vol. 1, Alter Ego Ing Arch, Firenze 2005, p. XIII. See also: PIAZZA M., CARABONI M., DE MARIA A., *Strutture in Legno*, Milano 2005;

4) This drawing form part of a collection of the sketches of all the wooden trusses of the roof structure of the church of Santa Maria de los Reyes in Grijalba, Burgos (Spain), and were done before the Restoration project designed by S. Perez Arroyo and Susana Mora, for the Junta de Comunidades de Castilla-Leon, 1995;

5) BRUNETTI G., *Tecniche non distruttive per la diagnosi,* in *Tecniche della Conservazione,* a cura di A. Bellini, Milano 1986, pp. 228-274.

ABBASI J., *Consolidation of historical woods using polyvinyl butyral/zinc oxide nano-composite: investigation of water absorption, wettability, and resostamce to weathering*, in International Journal of Conservation Science, Vol. 11, n. 1, 2020, pp. 15-24.

CEN, EN 338, *Structural timber – Strength classes. Technical report,* European Union, 2016.

DEFUS A., POSSENTI E., SANSONETTI A., TEDESCHI C., *The effectiveness of di-ammonium hydrogen phosphate (DAP) consolidation treatment on lime-based mortars weathered by freeze-thaw cycles*, in Journal of Cultural Heritage, Vol. 50, 2021, pp. 1-12.

MOUTON B., *Méthodes d'analyse destructives et non-destructives pour les structures historiques. Avantages et limites,* in *Stable – Unstable?*, pp. 141-146.

VANNUCCI P., *A study on the structural functioning of the ancient charpente of Notre-Dame with a historical prospective*, in Journal of Cultural Heritage, Vol. 49, 2021, pp. 123-139.