

NDT FOR THE CHARACTERIZATION OF A MONUMENTAL BUILDING OF THE FIRST HALF OF THE 20th CENTURY: THE OSSUARY TEMPLE OF BASSANO (ITALY)

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Abstract

On the occasion of the 100th anniversary of the end of WW1, the Italian Presidency of the Ministers Council has planned a wide series of conservation and valorisation works for buildings and monuments dedicated to the memory of the war victims. Among them is also included the restoration work of the Ossuary Temple at Bassano del Grappa (VI - ITALY). The building, which is the burial place of 5405 soldiers who died during the fighting on the nearby Grappa front, is actually shaped as a great church built between 1908 and 1934. Its construction, carried out in several stages, has consequently resulted in many interruptions and modifications, with changes of material, constructive techniques and also decorative and constructive programs.

The identification of these changes and of the consequent problems and decays, required a diagnostic campaign for the study of original materials, degradation pathologies and conservation materials that could respond to the many doubts about the methods of connection of many of the church's decorative elements (e.g. capitals, pinnacles and ribs), as well as the effectiveness of consolidation work carried out over the last decade. The diagnosis required the use of NDT like visual inspections, thermographs, electromagnetic and ultrasonic tests as well as SDT (Slightly Destructive Test) like endoscopic and physical/chemical tests. The results were obtained through a combination of different methodologies and provided significant information on the conformation and degradation of the artefacts, resulting in a case history applicable to other monumental buildings built with similar techniques during the first half of the 20th Century.

Key words

Thermographs, electromagnetic and ultrasonic

1 Introduction

To celebrate the centenary of the First World War, the Italian Presidency of the Ministers Council has set up a Mission Structure for Anniversaries of National Interest aimed at assuring the necessary requirements for the implementation of the program, the commemoration work and the related communication and promotional activities. The Mission structure is currently treating the restoration and structural improvement of the great monuments created at the end of the war to celebrate the victory and the memory of the slain soldiers.

At the end of WW1 there was the need to give adequate burial to the thousands of slain soldiers who, after the fighting, had been hastily buried in hundreds of improvised cemeteries in the places closest to the battlefields. Among other things, this circumstance well fulfilled the interest of the Italian fascist regime that set the celebration of the myth of war at the basis of its propagandistic program. For this reason, large monumental buildings were also built; they were called "Memorials" if they were located close to the combat fronts (among them Redipuglia, Asiago and Cima Grappa "Memorials") and they were called "Ossuary Temples" if they were located within urban centres; the last ones were intended for collecting the remains of the soldiers that had died in the hospitals located on the backlines.

The Ossuary Temple of Bassano has a peculiar history as, unlike other structures, it was not built ex-novo, but it was built readapting a building already under construction in the city of Bassano, that originally was intended to be the new cathedral. There were more than 5,400 slain soldiers buried there,

who had previously been buried in 46 cemeteries scattered along the mountain front in the city district; to collect the dead soldiers' bones, niches were built adapting the crypt and side altars.

1.1 Historical information

The construction of the new cathedral of Bassano started in 1908 following the project of the Venetian architect Vincenzo Rinaldo; the design complied with the Venetian neo-Gothic style. Few years later, the works were suspended due to the lack of funding and the interruption was further extended due to the economic problems resulting from the Libyan war and then for even longer because of the events of the First World War, when Bassano was the first backline of the Grappa front and was strongly bombed by Austrian cannons.

The works for the construction of the cathedral were not resumed even after the end of the conflict, until, in 1930 an agreement was reached between the Bassano parish and the High Council of Government for Honour to the Slain Soldiers which was committed to end the work under the condition that the building had to be turned into a Military Ossuary. The architect Pietro Del Fabbro from Treviso made the project suitable to the new requirements (Fig. 1) and the building was completed and inaugurated in May 1934, under the presence of the heir to the Italian throne, Prince Umberto of Savoia.



**Figure 1 Prospective view drawn up by architect Pietro Del Fabbro (1930),
The effects of World War II bombings on the temple facade**

During the Second World War, the Ossuary suffered damage (Fig. 1) due to the bombings that completely destroyed the close-by Victory Bridge; the damaged areas were restored in 1948 and in 1951; during the following years, atmospheric events caused the fall of some pinnacles on the crowning of the façades, which were therefore removed.

Further restoration works were carried out during the 70s and 80s; the last works, which were completed in 2011, were aimed at eliminating the damage caused by the abundant water leakages and resulted in the remake of roofs, the revision of meteoric drains and the restoration of damaged surfaces and decorative elements, especially in the lantern area.

1.2 Description of the building and of the construction techniques

The temple measures 75 m in length and 43 m in width at the transepts. It is divided into three aisles of different heights, parted by two rows of columns made of marble taken from Grappa Mountain. There are transepts (which have the same height as the central nave) and a deep presbytery also at full height. Symmetrically arranged on the sides of the presbytery, there are the two smaller altars, with a reduced depth, and two stairways to go down into the crypt. The ceiling is rib vaulted, embossed and plastered. At the crossing the octagonal dome rises, whose interior surfaces are decorated in a way similar to the walls of the presbytery. Outside, at the sides of the apse the two bell towers rise to a height of 60 m.

The Temple was built in several stages, so it is extremely composite, including masonry elements, stone columns, wooden cover beams, R.C. and steel elements. The structure consists of pilasters and stone columns and brick walls; the rib vaults are made of slender bricks reinforced by brick ribs that protrude to

the extrados. The external surfaces of the walls are completely made with brick masonry with no noticeable discontinuity, except for the traces of the repairs of the damage caused on the main facade by the war (Fig. 1).

The main facade is overhanged on the cusp with a soft stone cross and it has three portals made with "Pove" stone and three rose windows made with "Berici Mountains" stone. Each of the side facades is marked by 6 mullioned windows lighting the aisles and six oculars illuminating the nave; the windows and the side portals have stone mouldings. The octagonal lantern is illuminated by mullioned windows on all sides. The bell towers have external surfaces made of bricks and large arc openings at the top of the tower.

The floor is made of marble with internal decoration with polychrome shapes; marble steps allow to go up in the presbytery area and to descend into the crypt.

1.3 Critical aspects related to the conservation of the building

Due to the fact that the building has been built in several stages, with different clients and according to different designs, its comprehension and conservation is complex. The in-depth observation of the building highlights how the undeniable monumental intentions have been achieved partly (in the lowest parts that are the more directly approachable and visible) by using costly materials such as stones taken from the Veneto quarries and partly (in the highest parts and therefore the more difficult to observe) using low cost items, gypsum, stucco, decorated plasters, arranged such in a way to imitate stone surfaces. It has to be admitted, however, that the finishes have been made in a very accurate manner, so that, from a remote observation, it is not possible to distinguish the real from the "fake" stone elements.

This complicates the conservation approach to the building because visible degradations need to be thoroughly analyzed to detect both the phenomena and the materials with which the affected element is made. Therefore, during the diagnostic, it was necessary to directly access the surfaces to analyze the temple's interior surfaces. This analysis could be performed with the use of Movable Work Platforms (39 e 25 m in height), while the outdoor activities were performed through rope access techniques in compliance with the procedures defined by the Italian national Health and Safety standard.

Currently, the conservation status of the internal surfaces of the building shows criticalities related with past meteoric leakages from the roofs. It is relevant to note the fact that following the last restoration works, that is to say 6 years ago, the internal surfaces have shown problems of salt formation, detachment of a capital and also the falling down of fragments of the decorative apparatus. These circumstances have highlighted the need to evaluate the overall conservation status of surfaces and decorative elements. In drafting the preliminary plan, the designers pointed out the following aspects:

- the interior surfaces of plasters show wide areas affected by salt formation, where it was also advisable to check whether the past infiltrations present were still active;
- the interior decorative elements made of natural or "fake" stone (columns, ribs, capitals, mouldings) in some cases had already detached or crumbled;
- the surfaces and decorative elements of the main facade, particularly the stone portals with their decorative apparatus, were, in some cases, very degraded on surface level;
- there were some elements of the bell towers extensively degraded such as the R.C. structures of internal slabs and stairs and the surfaces on the north side of internal walls..

2. Experimental investigations

2.1 Goals of the diagnostic campaign

The test campaign was aimed at analysing the problems briefly explained in the previous chapter. It was necessary to locate the materials making up the surfaces and decorative elements, to detect their way of installation and connection to the masonry, to analyse their degradation status and to evaluate the structural reliability of the connection elements.

To pursue this goal, the combination of different NDT techniques (VT, GR, TT, PS, EL, PZ, UT - acronyms are explained in Table 1) were extensively used which provided qualitative data which, in some cases, had to be verified by means of SDT (PC, EN, SS, CH - Slightly Destructive Test). In Table 1, the applied techniques are outlined and matched to the relevant problems.

Table 1 - experimental activities carried out on the building

acronym	experimental investigation	internal surfaces	decorative elements	facade	bell towers
VT *	visual inspection	X	X	X	
GR *	georadar			X	
TT *	thermography	X	(X)	X	
PS *	seismic hazard			X	X
EL *	electromagnetic meas.	X	X	X	X
PZ *	corrosion potential meas.				X
UT *	ultrasonic measurements			X	X
SO	sonic measurements	X	X		
PC	depth of carbonation meas.				X
EN	Endoscopic surveys	X	X	X	
SS	stratigraphic essays	X	X		
CH *	chemical analysis	X	X	X	X

The main problems affecting interior surfaces are related to the presence of extensive areas with salt formation and to the localized detachment of plaster. They are clearly related to the copious meteoric water leakages that occurred until the restoration of roofs in 2011; the evaluation of the effects of such leakages in terms of degradation and detachment of the plaster is highly useful, and also the evaluation of the possibility that they are already active. Moreover, the efflorescence phenomena detected on large surfaces, for example on the walls above the transept arches, are difficult to understand as it is difficult to justify the capillary rise of humidity in those areas.

To analyse those surfaces direct visual inspection complete with sonic analysis was carried out. Thermography was also carried out and the current shots could be compared with available previous shots taken in 2009. In the anomalous areas detected by thermographs, endoscopic surveys allowed for the verification of the local situation; this analysis was also integrated with electromagnetic measurements aimed at providing the exact location of metal elements embedded within the masonry (tie-rods or rebar). The endoscopic surveys allowed for the evaluation of the thickness of the wall layer, particularly the structural thickness of the vaults.

During the test campaign *the analysis of the main architectural and decorative elements* was the most interesting and diversified aspect. That's why in the areas where close vision of the surfaces is not possible, the decorative elements are effectively made with gypsum, stucco or plaster with a finishing that imitates the stone. We refer particularly to:

- some of the crossing pillars, which in the upper part are made of masonry covered with stone slabs;
- the pilasters, which are mostly made of masonry plastered with "fake stone" finishing ;
- the capitals, which are made partly of stone and partly of plaster and stucco;
- the mouldings, which are mostly made of plaster, gypsum and stucco with "fake stone" finishing;
- the pilaster ribs, which at the bottom are made of stone and in the upper part are generally made of hollow gypsum;
- the vault ribs, which are made of hollow plaster and at the top are shaped with gypsum.

The analysis was carried out by direct inspection, with sonic measurements aimed at testing the uniformity of the elements and electromagnetic surveys to detect any non-visible pin and other metal fastening elements. Thermographs, which have also been taken for these elements, have in this case

proved to not to be efficient since the images could not be interpreted in an unequivocal way, presumably for the small size and the geometric superficial shrinkage of the elements. The effects of the most apparent degradation phenomena were then analyzed by taking samples that were subjected to physico-chemical-petrographic laboratory analysis.

The analysis of the main facade implied a general inspection of the conservation status and stability of its decorative elements (mouldings, hanging arches, rose windows), especially of the decorative elements of portals that are evidently subject to superficial degradation. The visual inspection of these elements was possible only through the use of access and positioning techniques by ropes (Fig. 2).

The overall status of conservation of the facade was evaluated through thermography. Its behaviour under environmental vibration, especially due to the vehicular traffic of the facing road, was determined by vibratory measures performed along one of the slopes; even in this case transducers could be placed only by operating by rope access techniques (Fig. 2).

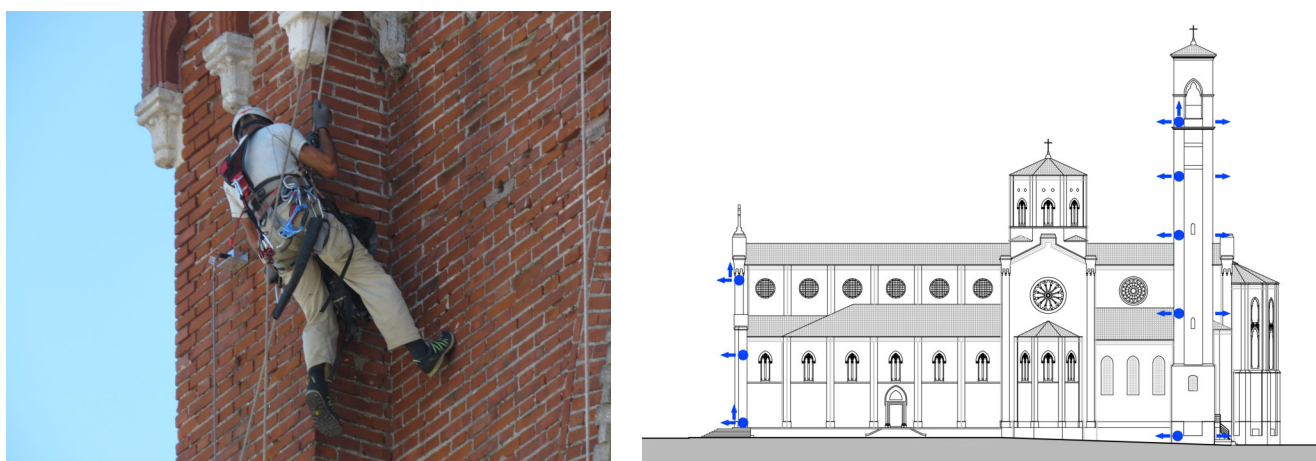


Figure 2 Placing of the sensors with rope access techniques, sketch of sensors position

To evaluate the conformation and the clamping of the stone elements of the rich decorative apparatus of the main portals, ultrasound tests were carried out that allowed for determination of their homogeneity, electromagnetic and geo-radar measurements were taken, to locate the connecting elements, and endoscopic surveys done, to directly detect the presence of pins and any non-metallic elements not otherwise detectable.

The analysis carried out on the bell towers concerned the assessment of the conservation status of the internal floors and stairs, partly made with wooden beams and planks and partly with R.C. slabs. For this purpose, measurements of corrosion potential were taken, with depth of carbonation and electromagnetic analysis aimed at locating and estimating the dimension of rebar. Furthermore, on the masonry physico-chemical-petrographic analysis was performed aimed at evaluating the effects of the degradation phenomena connected with the efflorescence systematically present on the inner face of the northern side of each bell tower.

Vibratory measurements (Fig. 2) were also performed to evaluate the magnitude and effects of the vibration to which the two bell towers are subject, in connection with the different sources of this (environmental, traffic, bell movements). Taking into account the current structural situation (geometry and boundary conditions) it was possible to determine the relative frequency range and the dynamic characteristics of the structures (the proper frequencies of the first modes of vibration); the results were also used to determine the structural dynamic characteristics of the two towers.

3. Results

3.1 Interior surfaces

The thermographic analysis of the interior surfaces of the temple (Sept. 2016) was performed with stationary conditions and a passive approach, the temperature and rainfall data of the quarter before the execution of the measurements was checked, and furthermore, the parameters of micro-climate were monitored throughout the month of September by means of two hydro-thermic probes connected to a data-logger that allowed the hourly acquisition of data. For the shooting of thermal images an uncooled infra-red thermovisual FPA system was used and micobolometric operating in the long field (LW 8:14 μm) with spatial resolution 1.3 mrad and emissivity set to 0.92.

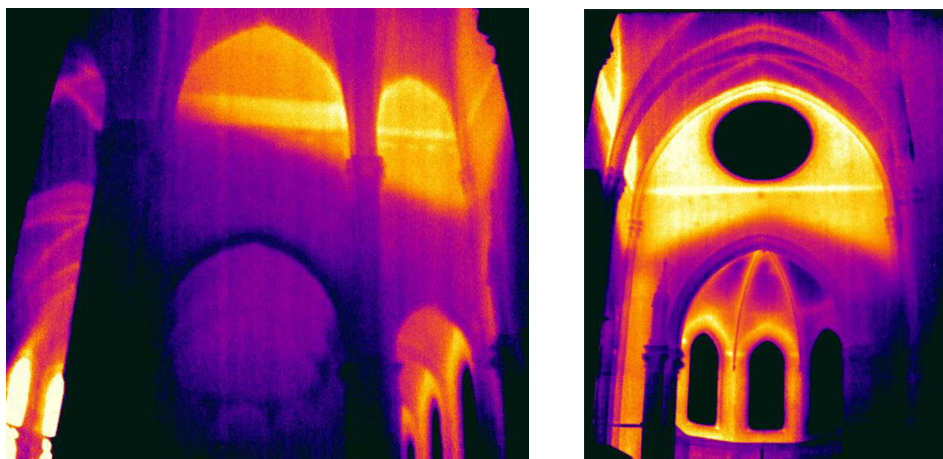


Figure 3. Thermography of the south side and west side of the western transept

For the purpose of localization of wet areas, the abnormalities of negative gradients (colder areas) were located and analysed. Thermal analysis of thermograms, comparison with the conservation status of the surface and analysis of the environment allowed the evaluation of the typology of detected anomalies. In areas that were at a lower temperature and in areas of evident degradation, samples were also taken to carry out gravimetric measurements and analysis of soluble salt content.

Through the thermographic survey, some significant information about the construction techniques were obtained. In the two transepts, for example, the presence of linear high thermal conductivity elements embedded in the masonry body (Fig. 3) were evident: on the basis of subsequent surveys carried out by endoscopy and electromagnetic analysis, the horizontal element, 100 cm in height, was identified with reinforced concrete beam, and its geometry and structural rebars were exactly detected. Other punctual thermal anomalies visible in the same images should be correlated with the unusual presence of stone elements embedded in the masonry.

The comparison with the shots recorded in April 2009 confirmed that the roof restoration works carried out in 2011 removed the meteoric water leakages. Only few spots, however circumscribed, can currently be regarded as wet: their humidity was confirmed by gravimetric measurements, specifically in the samples taken on the inner surface of the lantern and on the inner surface of the main facade close to the portals. On the wall of the nave, on the contrary, the leakages that in the past caused the wide-spread spots are currently exhausted, as confirmed by the thermographic shots further supported by gravimetric measurements.

3.2 Interior architectural and decorative elements

Close inspection confirmed that the main architectural and decorative elements of the building (arches, ribs, lobes, capitals, moulders) are made in such a manner to look similar to stone, but they are composed alternately with stone elements (blocks or slabs) and elements with plastered masonry, stucco or gypsum. One of the main purposes of the analysis was to determine these elements' construction methodology and fastening to the masonry. This was done preliminarily by visual inspection, in order to distinguish the material and consistency of the elements and to evaluate their degree of detachment; the analysis was

subsequently deepened by electromagnetic and endoscopic surveys to determine constructive modalities, to evaluate embedding/fastening and to define the conservation of the elements.

The arches are made with two different constructive typologies: stone blocks or plastered masonry. All the arches of aisles and the arches between aisles and nave are made with stone blocks; the electromagnetic analysis did not identify the presence of specific metal fastening elements, but neither detachment. The other arches are made of brick masonry covered plasters (only in one case hollow brick elements have been identified); even in this case, the electromagnetic analysis did not reveal the presence of metal fastening elements.

The rib vaults are made with bricks set in place with “sheet” texture, with a structural thickness of $4 \div 6$ cm. Thermographic shots have highlighted some areas subjected to possible plaster detachments; in some locations there are also cracks, however limited, which were individually located and mapped. Each vault rib is made with bricks arranged with “knife” texture that have been shaped in a circular section with constructive techniques varying according to the height. The instrumental analysis proves that the structural ribs have a bend radius different from the vaults.

The two North pillars of the crossing are entirely made with grey sandstone blocks, while the two South pillars, on which the presbytery triumphal arc is supported, are made, in the upper part, with brick masonry covered with stone slabs. The electromagnetic analysis detected that these slabs are fixed with metal pins clamped in a slit on the edge of the plate; their correct consistency has been verified by endoscopy. Even the ribs at the edges of the pillar are connected to the masonry in a similar way.

For the dome stucco moulders, degradation is very advanced. The modern materials used for the last refurbishments apparently do not permit proper breathability and have resulted in film formation and progressive detachment. In this area saline efflorescence are widespread both on the plastered walls and on the serial gypsum and plaster elements; degradation has generated phenomena of disintegration, detachment, erosion and exfoliation. The destructive power of the salts against these artefacts is clear on the surfaces affected in the past by moisture penetration where they caused the current efflorescence phenomena.

Over recent years, this degradation caused relevant detachments; so that also during the inspection, it was necessary to remove some dangerous detached and unsafe elements. Instrumental analysis has not detected any fastening elements: the gypsum moulders are barely embedded in the plasters and the corner corbels are barely glued on the plaster surfaces, so that some of them were already detached and have dropped down.

The physico-chemical-petrographic analysis had a twofold purpose of verifying the type of material constituting the building (plasters and finishing) and to characterize the degradation related to the presence of humidity or salt. The higher values of humidity content were detected on the internal surfaces of the dome and of the transepts. In some locations of the dome, a higher moisture concentration was found in the inner part of the masonry rather than the outer part: this indicates that the moisture is due to infiltrations from outside.

Measurements of soluble salts were also carried out at all spots where humidity measurements were performed. The presence of soluble salts of the anionic sulphate species was mainly detected; from diffractometric analysis these species were identified as magnesium sulphate. The greater concentration of salts, with a degree of contamination that can be classified “severe”, is, also in this case, at a sampling point located in the dome. Concentrations of salts classified as “medium”, however, matched with visible damage were still detected in dome and transepts. The other samples all have a contamination of soluble salts which can be classified “mild”.

3.3 Decorative elements of main facade and portals

The access to the external surfaces of the main facade (situated at the North side of this church) was possible only by rope access techniques. The top of this facade is marked by the presence of moulders and hanging arches made with adobe and of stone corbels; they appear to be well conserved and well fastened. At the level of the rose window, in some cases, the surface shrinkage of bricks was observed, but it does not seem active at this time.

The three main portals are shaped with pedestals, pillars, pinnacles and pediments made with white “Pove” stones. Above the moulder of the portals, many fragments that were already detached and fallen were recovered, so it was necessary to further analyse these elements, with the purpose of detecting the connection methodology between the portals and the masonry and the mutual coupling of the stone elements. The analysis pointed out that the pedestals and pillars are clamped for about 5 cm in the masonry; the pinnacles are separated for about 5÷10 cm from the rear masonry. The pediment is made with stone at the front and is clamped with metallic pins to concrete elements placed on the back.

The analysis of the mutual matching of the stone elements outlined the presence of small lead plates laid in horizontal joints as assembly devices. Electromagnetic interference, meant that electromagnetic techniques in connection detection were ineffective, so it was necessary to carry out a radar survey.

Geo-physics radar was used with emission frequency to 400 kHz and antenna with nominal frequency 3 Ghz. For synchronism in the output of the signals, a wheel with an encoder directly assembled on the antenna was used. The joints between the individual elements that make up the portals were investigated by performing, for each of them, horizontal lateral and front scans; vertical scans were also performed at both the piers of the masonry facade.

Finally, ultrasonic measurements were made on the stone elements of the pillars and pinnacles of the main portals in order to evaluate their consistency and conservation status. These measurements have been drawn up by determining their variability and average value.

3.4 Dynamic behaviour of the bell towers

Dynamic tests were performed measuring the effects of the vibrations both of environmental origin or due to traffic or to bell movement. The transducers network was placed such in a way to allow the evaluation of the magnitude and the distribution of the vibratory phenomena and to detect modal parameters with sufficient precision. Acceleration sensors were placed, for each bell tower, in 5 horizontal sections plus in the lower and higher section. The data, logged for each configuration for about 1 hour, were analysed both in the domain of time, to obtain the maximum vibration values recorded (in terms of acceleration and velocity) and in the domain of frequency (spectral and power density) to obtain the frequency range of interest and the modal characteristics of the structures.

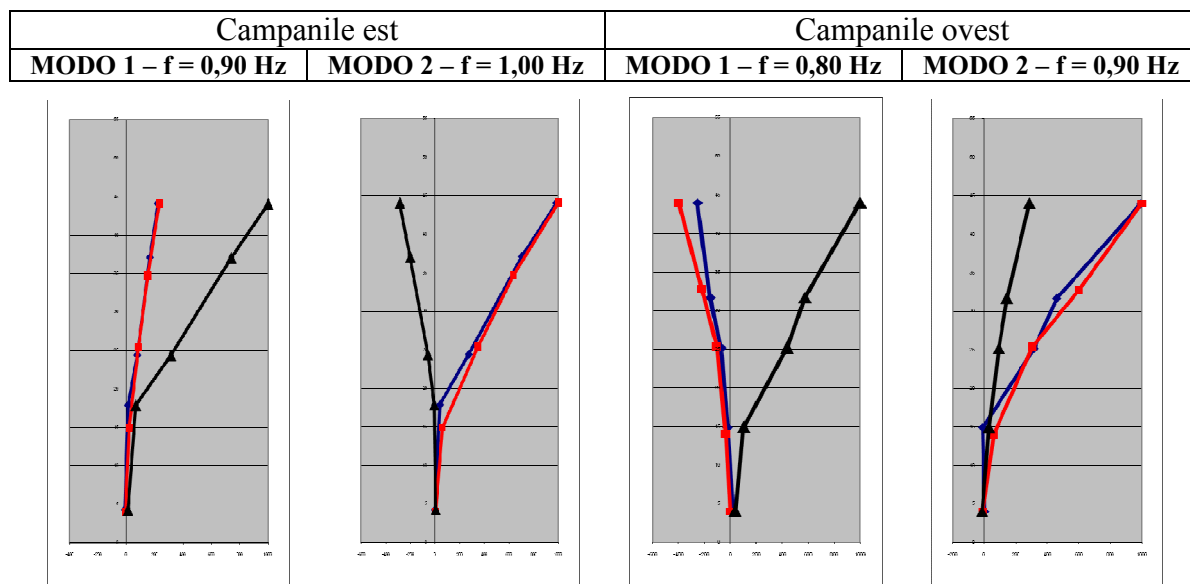


Figure 4. Modal diagrams of the prime two vibratory modes of the two bell towers

The analysis was able to compare the dynamic behaviour of the two bell towers that are quite similar because of their geometry and boundary conditions. The analysis has been done taking into account 250 Hz sampling in both the cases; the recordings made with and without the movement of the bells were analysed separately. Thus, it was possible to detect the top five vibratory modes of each bell tower; which, while not having equal frequencies, correspond with regard to the type of vibration.

The analysis of the distribution of detected vibration frequency content shows that bells mainly respond to environmental noise factors in the first two ways of vibration, while being less sensitive to other frequencies. Modal diagrams (Fig. 4) show that movements are prevalent in horizontal directions.

Modal parameters of the detected modes are estimated with sufficient precision (the coherence values in the determination of the transfer functions are generally good, that means above 0.85, for the East bell tower and are lower for the West bell tower). The horizontal modal diagrams are regular. It is necessary, however, to underline the high values of modal damping (for the top two vibratory modes it is, respectively, 4% and 5% for East bell tower and 3,5% and 3% for West bell tower, while for the following modes it is always lower than 1,5%). This is meaningful if we take into account the low excitation level applied during the measurements: in this condition such factors (low coherence value and high modal damping) contribute to indicate an abnormal behaviour, especially for the West bell tower.

4. Conclusions

Direct access to the surfaces with the use of Movable Work Platform to detect the internal surfaces or by access and positioning systems through ropes for the North facade proved to be effective in gathering a great amount of information about the conservation status of the building that aids in providing the picture of the overall situation. This is essential as a basis for the following design phases.

NDT analysis was matched with SDT analysis to obtain the complete characterisation, both qualitative and quantitative, of the heritage building. Thus, it was possible to report on the plants and sections, the relevant information concerning the characterization of the architectural and decorative elements and the degradation and clamping status of the arches and ribs that were acquired by inspection and analysis of the surfaces.

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