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The use of georadar to assess damage to a masonry Bell Tower in Cremona, Italy

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Abstract

Frequently, the application of NDT (non-destructive testing) to historic buildings is needed in order to search for hidden parts of the structure or for structural faults. The designer who requires the investigation is always facing the difficult situation of accepting the interpretation of the results given by the NDT experts, who in turn are usually only exceptionally expert in material and structures. Only a strict collaboration between the designer and the experts and the use of different investigation techniques, from the simplest to the more sophisticated can help in the interpretation of the results.

The application of georadar to the detection of three main structural problems for the Bell Tower (Torrazzo) of Cremona is presented, together with the description of the difficulties in acquisition and data elaboration and the description of auxiliary investigations used to validate interpretation of the results.

Keywords: Masonry structure; Diagnosis; Non-destructive techniques; Delamination; Hidden elements

1. Introduction

The importance of applying different techniques of investigation and of careful elaboration of the collected data in order to solve difficult problems connected with the diagnosis of structural problems associated with historic buildings has been pointed out several times [1–3,5]. In fact, when using NDT (sonic, georadar, thermovision) to detect hidden damage, voids or inclusions, one of the greatest difficulties is the interpretation of the results, even when accurately presented. Radargrams, tomographies, etc. might contain important information, but they are usually readable only with great difficulty by the designer. Therefore, the designer who has asked for their application, has to accept the interpretation given by the NDT experts, who frequently are not experts in materials and construction techniques applied in the past. Therefore, there is a need for a better evaluation and connection of NDT results to the reality of the structure, which can be helped by a clear presentation of the results themselves.

Aware of these needs the authors of this paper have been working on the application of georadar and other tests to the diagnosis of the Torrazzo of Cremona, trying to produce radar images that relate directly to structural problems representing the target of the investigation. This work was performed with close co-operation between the experts in radar technology and the experts on historic buildings involved in the diagnostic actions for the tower.

A first investigation was made to find and define the extent of the detachment of the thin external leaf of the load bearing wall. The wall was surveyed with a high frequency antenna along many parallel profiles so that a 3D reconstruction of the external part of the wall was possible. The results were calibrated with local inspections and were correlated with the crack pattern to understand the causes of damage. A second investigation was made to understand the morphology of an arch where the inspection of a scaffolding hole was suggesting that the external masonry leaf hides an arch with a shape different from the shape shown by

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the external brick work. Again, a 3D GPR survey was performed and interpreted with the help of the masonry building experts. Finally, a third investigation was made to detect the hidden structure of the concrete frame supporting the bells. The data were acquired with a high frequency antenna along a network of orthogonal profiles. The results were correlated with the local information obtained from coring and video camera observation.

2. Building and problem description

The Bell Tower, called 'Torrazzo' by the Cremona citizens, is adjacent to the Cathedral (Fig. 1); the date of construction is not well defined and may be either in the 8th or in the 13th century. The tower, probably the tallest Medieval tower in Europe, is 112 m high. Its structure consists of a square plan part up to 70 m and a framed structure called 'Ghirlandina' with an octagonal plan and topped by a spire, from 70 to 112 m. The staircase from the ground to the Ghirlandina level was built within the thickness of the walls (approximately 3.3 m). The staircase also allows the access to some internal rooms. Along the staircase which is covered with a barrel vault, the thickness of the external wall is about 1 m while the thickness of the internal wall ranges from 0.7 to 1 m, being the span of the staircase being 1.3–1.6 m.

Fig. 1. Picture of the Bell Tower of Cremona (Torrazzo).

Archive documents testify that the Torrazzo was subjected to many restoration works through the centuries, especially the upper Ghirlandina. The last important works were carried out in 1977 on the Ghirlandina by Saracino [6], an architect of the Cultural Property Office in Milan. The works performed were the following: (i) reconnection of the structural and decorative elements, (ii) construction of a concrete frame supporting the twin columns of the internal 'Stanza delle ore' and the bells (at a height of 85 m), (iii) cleaning and surface treatment with epoxy resins of brick and stone surfaces.

Several signs of damage such as cracks passing through the wall, and surface deterioration appearing on the tower walls suggested the need to carry out a laboratory and on site investigation to check the safety of the tower. In October 1997, a contract was signed between the Council of Cremona Cathedral and some Departments of the Politecnico of Milan. The investigation concerned several aspects: (i) geometrical survey, (ii) survey of the crack patterns and of the deterioration distribution on the internal and external surfaces of the walls, (iii) characterisation of the materials through chemical, physical, petrographical and mechanical tests, (iv) on site measurements of the state of stress caused by the dead loads and of the stress–strain behaviour of the load bearing walls, (v) use of sonic pulse velocity and georadar investigations to detect the existence of an external masonry leaf (a sort of veneer one brick thick) which was suspected of being detached from the rest of the wall, and therefore susceptibly subjected to possible dangerous local failure.

In addition to the above mentioned tests a computer-controlled monitoring system was installed to record changes in the patterns of damages. Unfortunately the system only worked for a short period.

The geometrical instrumented survey allowed the building of a 3D model of the tower; the surveyed crack pattern was carefully reported on the geometrical survey [4] (Fig. 2). Vertical cracks are present on all sides of the tower and extended from the top of the base up to the top of the square part. Furthermore, the Ghirlandina showed the most important cracks on the buttresses and on the brick columns. Also, the internal part of the tower along the staircase and inside the internal rooms showed a diffuse crack pattern and some cracks extending through the walls.

The presence of the detachment of the external leaf was noticed on several parts of the tower. Cores from boreholes and video camera internal observation also showed this phenomenon (Fig. 3). Due to the large thickness of the tower's external walls it was necessary to match the results of local tests (such as boroscopy and flat jack) to ND tests