

A GPR Survey of the Floor of the São Carlos Theater (Lisbon, Portugal)

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Abstract – This paper describes a study conducted by LNEC to assess the health and safety conditions of the floor of the Noble Hall of the National Theater of São Carlos. In a multidisciplinary approach, an extensive field work was carried out, involving the identification of type and location of floor beams in the various areas of the floor using a Ground Penetrating Radar (GPR), local inspection openings to visually assess the geometry, timber species and conservation state of structural members at those points and assessment of the conservation state of timber beam ends, using drilling equipment. The tests performed are referred herein, the potentiality of using GPR, the results obtained with ground- and air- coupled antennas are analyzed and recommendations are made.

I. INTRODUCTION

The cultural heritage of a country it is an important asset for its identity. The protection and management of cultural heritage includes materials characterization, archaeological prospecting or structural stability analysis. The preservation of the heritage has to be undertaken continuously and with proper measures in order to perform a cost-effective maintenance and to guarantee its integrity.

Non-destructive tests are important tools for diagnose the condition of cultural heritage. There are some different geophysics methods used for subsurface inspection, including magnetic, electrical and electromagnetic methods [1].

The Ground Penetrating Radar (GPR) is one of the most recommended non-destructive testing (NDT) techniques because of its fast data acquisition and high-resolution imaging [2-4].

This paper presents non-destructive surveys performed with different GPR antennas in order to identify the structure of the floor and to evaluate its bearing capacity. The impossibility of demounting the floor without damaging the decorative wood surface layer

and the lack of historical data regarding the floor structure and the repair works undertaken since its construction were two reasons to use GPR technique for a better monitoring. The main results obtained and the efficiency of different GPR systems used are presented herein.

The purpose of this study was to evaluate the state of conservation and safety of the timber floor structure of the Noble Hall of the National Theater of São Carlos (TNSC) in Lisbon, Portugal. According to the information available at www.monumentos.pt and <http://tnsc.pt/>, the National Theater of São Carlos was inaugurated on June 30, 1793. This neoclassical, 18th century building of Italian inspiration was classified as a public interest property in 1928 and became National Monument in 1996. It is known that it received a great intervention in 1938/1940 and several other interventions later. However, it was not possible to obtain precise information about the construction system of the floor of the Noble Hall (Fig 1).

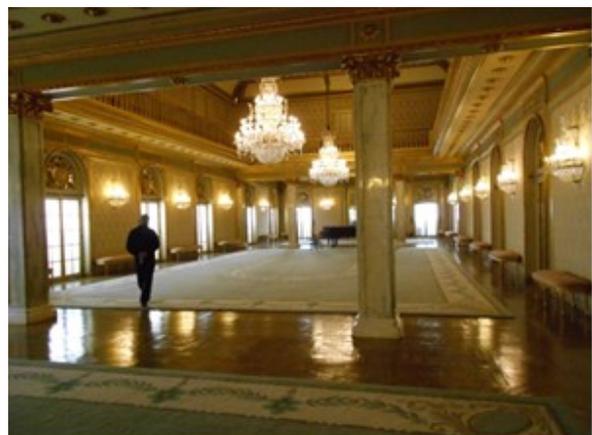


Fig. 1. General view of the Noble Hall.

Consequently, it was agreed to carry out surveys to identify the geometry of the structural elements and other

relevant constructive aspects and to assess locally the species, quality and conservation status of the wood used in the floor structure.

In order to identify the floor structure geometry, a non-destructive survey using GPR was performed to identify the location and material of the structural elements [5].

In order to clarify some specific situations not covered by the surveys, namely in terms of the state of conservation of the wood, measurements were also made with the drilling equipment, covering the ends of some main timber beams [6].

II. VISUAL INSPECTION AND NDT EVALUATION OF WOOD BEAMS

Openings for visual inspection were carried out at four points of the Nobel Hall pavement, through local cutting of the floor (see Fig. 2). The observations made allowed to confirm that the decorative floor rests on a flat multilayer structure (the total thickness of the several layers that make up the floor is about 50 mm), which contributes to the redistribution of loads and to the stiffness and bearing capacity of the floor.

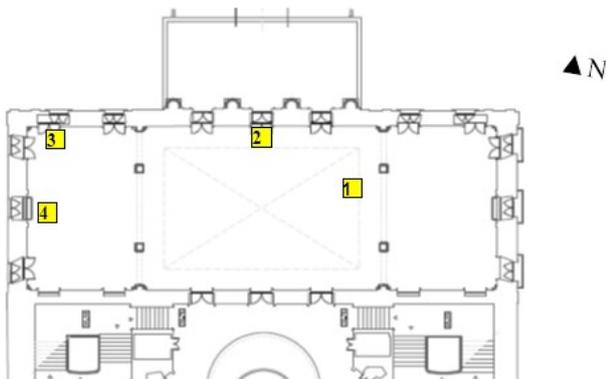


Fig. 2. Draw of Noble Hall and location of the cutted samples.

The Noble Hall comprises three distinct zones: the central hall, of about 16.75m x 11.30m and the west and east areas, of about 7.75m x 11.30m each, with independent load-bearing structures. In the central hall, the floor structure consists of solid wood beams interspersed with metal beams arranged in the N-S direction. The wood beams, about 265mm high, have variable dimensions and spacing. In the east and west side, the structures of the floor are made of wood beams only, with variable sections and spacing from zone to zone, usually spanning between consecutive masonry walls.

The anatomical characteristics of the wood of the observed beams suggested that it was maritime pine (*Pinus pinaster* Ait.), which was confirmed through

laboratory analysis of wood samples collected from the beams, that also allowed estimating their density [7].

The inspection carried out in the central zone of the floor of the Noble Hall revealed that there are different structures to support the pavement and the roof of the entrance Lobby underneath. The resistant structure of this roof, in inverted casing, is mainly made of curved wood elements ("ribs"), supported directly on the exterior walls or attached punctually to the floor beams. As far as it could be observed, in the prospecting areas, the wood showed no signs of active infestation by wood boring insects or degradation by rot fungi or termites.

III. PUNTUAL VERIFICATION OF THE STATE OF PRESERVATION OF SUPPORTED AREAS

The state of conservation of the support zones (ends) of some wood beams on the north façade was verified by evaluating their drill resistance with the IML RESI B 300 equipment. This equipment performs a hole in the wood with about 3mm in diameter, allowing to obtain a variation profile of the resistance to drilling along the cross-section of the element.

The procedure used consisted of obtaining a resistance profile from the area of the beams just outside the support zone (drilling at 90°), a location normally unaffected by biological deterioration related with moisture, followed by obtaining another profile in the support zone (drilling inclined at 45°) (Fig 3). The test points were decided based on the location of the beams, estimated using the georadar.



Fig. 3. Test of resistance to drilling: outside the support (on left); next to the support (on right).

The results allowed to assume that the wood beams of the pavement are sound or without signs of significant degradation by fungi or subterranean termites. The differences in drill strength profile shown in Fig.4 are due to the difference between the needle inlet angle and the beam face (90 ° in the case of the test outside the supports area and 45° in that area).

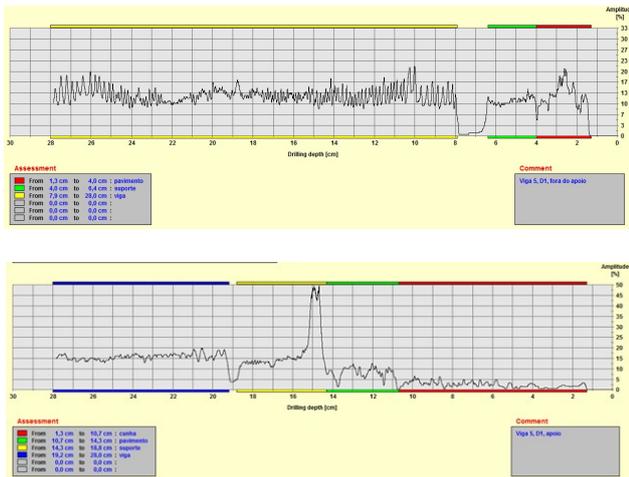


Fig. 4. Results of Beam 5: outside the support (on top); next to the support (on bottom).

IV. GPR ASSESSMENT

Different GPR systems were used including both ground- and air-coupled antennas (Fig. 5).

The ground-coupled system used was from Malå Geoscience company and it was composed of a Proex control unit and two bistatic antennas of 1.0 and 2.3 GHz. Data acquisition was carried out by distance with a trace-interval of 1.0 cm.



Fig. 5. GPR systems used.

The air-coupled system used was from GSSI company and it consisted of a SIR-20 acquisition unit with a bistatic antenna of 1.8 GHz. Data acquisition was carried out by distance with trace-intervals of 2.5, 1.0 and 0.5 cm (40, 100 and 200 scans/m, respectively).

V. RESULTS AND DISCUSSION

These tests allowed establishing the geometry of the structure, type and location of the beams in various areas of the floor. The information collected complements the direct measurements and the survey done by visual inspection. It was possible to set up a numerical model for further structural analysis based on the geometric information regarding the structure of the floor.

The data obtained with the ground-coupled antennas have produced radargrams with better resolution than the air-coupled antenna. Nevertheless, only the 2.3 GHz ground-coupled system has provided the configuration of either wood or metal beams (Fig. 6). The 1 GHz antenna presented a lack of detection in wood beams.

Regarding the 1.8 GHz air-launched antenna, only metal beams were identified when intercalated with wood beams. Whenever only wood beams exist, the method showed better response.

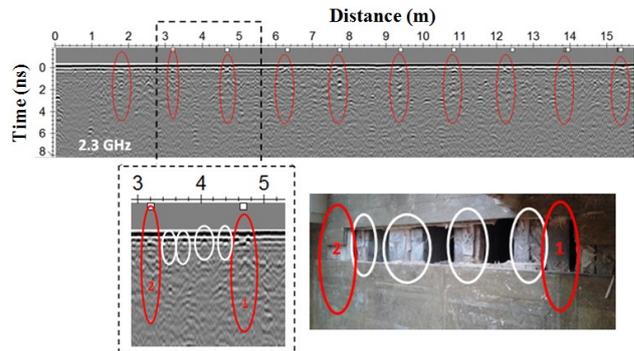


Fig. 6. 2.3 GHz data and detection of wood (white circles) and metal (red circles) beams.

Observing Fig. 7, a data acquisition based on 100 scans/m displayed better results than using 200 scans/m, which was certainly produced by an overlapping of the hyperbolic reflections due to the excessive closeness between scans. On the other hand, a poor number of scans, as the 40 scans/m used in this work, presents the risk of losing detection.

Additionally, several profile lines were acquired to determine the lower ceiling structure. Fig. 8 shows a radargram produced by the 2.3 GHz antenna in the longitudinal direction through the middle of the floor, which has revealed the existence of a centered vaulted skeleton. The data acquisition here was carried out by time, with a trace interval of 0.01 sec.

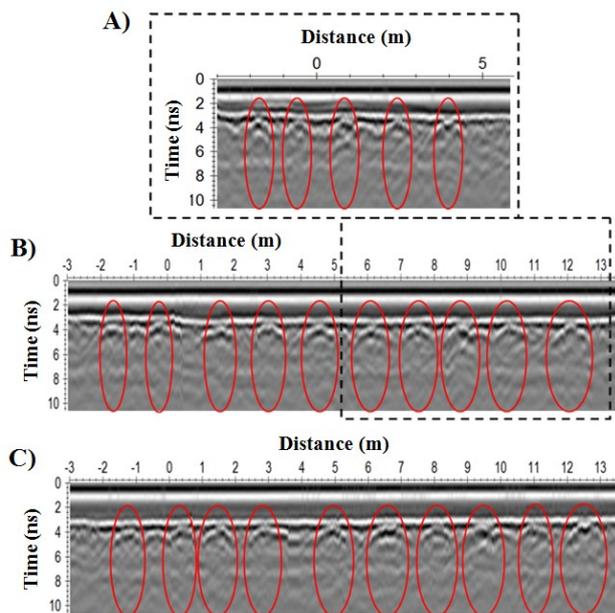


Fig. 7. 1.8 GHz data with 40, 100 and 200 scans/m (A, B and C, respectively) and detection of metal beams.

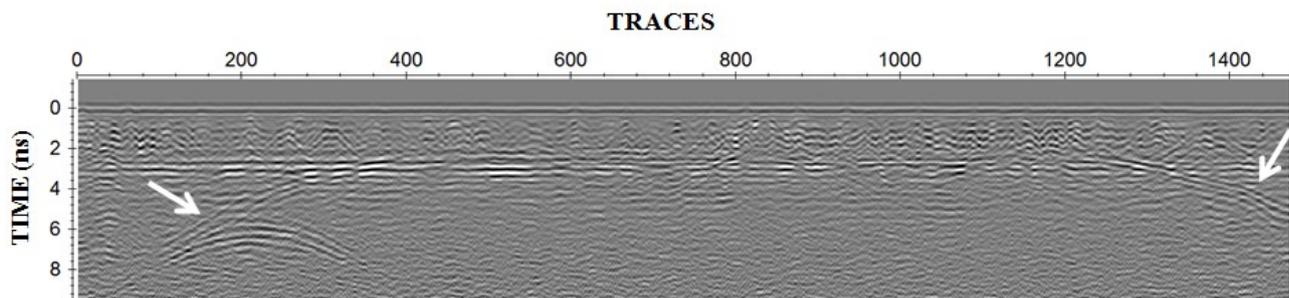


Fig. 8. 2.3 GHz data from the profile line acquired in the longitudinal direction at the middle of the floor.

VI. CONCLUSIONS

The comparison between the 1.0 and 2.3 GHz ground-coupled antennas has shown that both frequencies present capabilities to detect metal, but only the resolution of the 2.3 GHz was able to detect all the wood beams.

Regarding the 1.8 GHz air-coupled antenna, although better results were obtained when considering 100 scans/m, the image resolution was worse than for the 2.3 GHz ground-coupled antenna.

VII. ACKNOWLEDGEMENTS

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