

Non-destructive investigation of structural elements of the “Altes Museum” in Berlin

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Abstract

Strategies and methodologies for the assessment of historic masonry structures based on non-destructive and minor-destructive testing methods were developed in the European Research Project ONSITEFORMASONRY and were successfully applied to assess the structure and material properties of selected structural elements in the Altes Museum in Berlin-Mitte. For the planning of a broad reconstruction within the framework of a master plan concerning the whole of Museum Island in Berlin, several questions arose which are also typical for other historic structures in general, thus the Altes Museum was chosen as a pilot site for the validation of non-destructive testing methods.

Keywords: non-destructive testing, historic masonry, radar, columns, cupola, anchors.

1 Introduction

The “Altes Museum”, built between 1823 and 1829 by Karl Friedrich Schinkel, is one of the most important buildings of the Museum Island located in the centre of Berlin. The museum is part of the World Heritage. The “Altes Museum” was commissioned by King Friedrich Wilhelm III as the first public museum of Berlin and was the nucleus of the Museum Island, symbolising the cultural and political centre of Prussia. The building was designed having an atrium with



large pillars and possesses a central cupola resembling the Roman Pantheon. Antique temples served as an archetype for the exterior view of the building.

During the Second World War the “Altes Museum” was partly destroyed by bombs and fire. During the 1960 reconstruction works took place, which are not very well documented. In 1999, the planning stage started for a broad reconstruction in the frame of a master plan concerning the whole Museum Island. The planning took into account modern requirements for museum buildings. The investigations were mainly aiming at throwing light on previous repair interventions. Further inspections were connected with planned projects for reconstruction works in the basement (archaeological promenade) and the stabilisation of the building foundation, which is partly insufficient.

Two measurement campaigns were carried out as case studies in the frame of the European funded research project ONSITEFORMASONRY [1]. A multitude of complementary non-destructive (NDT) and minor destructive (MDT) methods like radar, microwave borehole transmission, active thermography, ultrasonics, sonics, geoelectric, videoscopy and flat-jack have been applied to answer questions which concerned the internal structure and technical parameters of columns, walls, floors and ceilings [2,3].

2 Objectives

The Altes Museum has been chosen as pilot site because several questions are also typical for other historic structures in general. In the frame of reconstruction, testing problems mainly occur related to the inner structure of different structural elements like columns, floors, ceilings and walls.



Figure 1: Left: Altes Museum, view from the Lustgarten. Right: Cross section of the Altes Museum showing the different construction elements in the entrance hall, in the rotunda and in the cellar.

In the following, the objectives of the investigations are described in more detail.

2.1 Column at the entrance hall

The outer column located at the west part of the entrance hall was selected for solving the following questions: How are the single drums connected to each other? Is it possible to locate the different materials used for restoration at the cylindrical shell? A scaffold was raised for performing measurements along the

whole length with radar and partly with ultrasonic and sonic methods. Radar and ultrasonic investigations in reflection as well as in tomographic mode had been planned.

2.2 Cupola of the rotunda

The cupola consists of brick masonry. The lower part is made in the form of a cantilever arch, the part above the ring of sand stone has the form of a dome structure. The upper part was constructed using light bricks (surcharge of charcoal and other materials), which are jointed with fast setting “cement mortar”.

Figure 2 left shows the assumption of the architects regarding the existence of a stone ring embedded inside the brick masonry structure supporting the dome. The objective of the investigations was to validate this assumption and to derive as many information as possible regarding the morphology of the ring. Thus, radar measurements had been carried out in reflection mode.

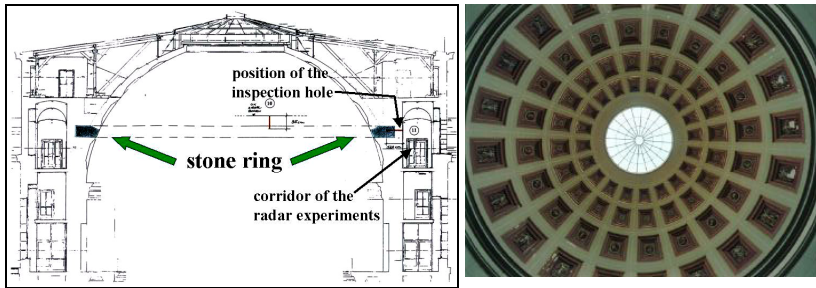


Figure 2: Left: Structure of the supposed reinforcement stone ring and position of the investigations. Right: View to the cupola showing the waffles.

The waffles visible at the inner surface of the upper part are made of gypsum stucco (figure 2 right). According to the available documents during the reconstruction the loose surface of the porous bricks had been cut down for about 3 cm. On the inside surface, a Rabitz granting has been mounted usable as plaster lath base. This granting has been fixed with anchors, which are passed through the masonry structure. The ends of the anchors are exposed on the outside of the cupola.

The objective of the investigations with radar, impact-echo, microseismic and geoelectric was to get more information about the inner structure of the masonry wall of the cupola and to detect the anchors, which are carrying the waffle slab. These investigations had been performed from the outer side of the cupola.

2.3 Floor of the rotunda

The floor of the rotunda as shown in figure 3 has a diameter of 20.7 m and consists of two different areas:

- Original floor with gypsum screed in the gallery and between the columns;
- Reconstructed floor with cement screed in the inner part of the rotunda (1981/82).

The original floor was built with different layers:

- 30 to 40 mm of gypsum screed,
- sand (adhered with anhydride),
- about 100 mm of clay.

In the reconstructed area, the old floor was removed down to the clay layer. The reduced clay layer was filled up with gravel and one layer of oil paper was positioned. On the oil paper, about 60 mm of concrete was anted up. Finally, the panel layer with a thickness of 20 mm was built in consisting of cement with lime stone gravel. Some small parts of the panel layer had been pre-cast. For crack stability, these parts had been reinforced with metallic bars.

One of the main aims was to find out differences between old and new parts of the floor. Additionally, voids below gypsum or cement screed had to be detected.

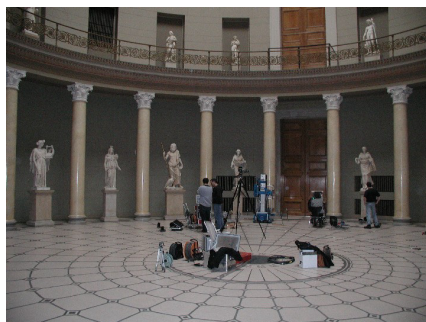


Figure 3: Floor of the rotunda during the measurement campaign.

3 Results

3.1 Columns of the entrance hall

Mainly radar investigations were performed at the column. Radar is based on the transmission of short electromagnetic impulses by an antenna at frequencies between 300 MHz and 2.5 GHz [4]. These impulses are reflected at interfaces with changing dielectric properties of the materials. Also the propagation velocity depends on the dielectric properties. Since moisture is influencing this parameter, radar can also be applied to detect an enhanced moisture content and to determine the moisture distribution. With radar, reflection measurements from one surface as well as tomographic measurements from both sides are usually performed to obtain information about the internal structure of the structural element under investigation [5–7].

For getting an overview traces in direction of the longitudinal axis (vertical) of the selected column were recorded with the 900 MHz antenna along the whole height (10.2 m). A measuring wheel mounted to the antenna performed path recording. Figure 4 shows one of these radargrams. Clear signals related to the surface and to the backside reflection can be detected. The travel time of the backside echo increases when going from top to bottom corresponding to an increase of the diameter of the column. Close to the surface reflection, hyperbolas occur representing the reflection of the joints between the different drums. Due to the high intensity of these reflections, it is assumed that these joints contain plumb layers that were used as a non-seizing compound for the alignment of the column drums.

For detailed investigations on the joints between the drums, horizontal traces at different areas close and far from the joints were recorded. The measurements were performed radial along the surface of the column with the 1.5 GHz antenna. One of these radargrams below a joint is shown in the bottom of figure 4. Due to the cannelures the backside reflections appears in a wavelike shape. Noticeable reflections can be detected at a depth between 70 and 75 cm. The position and intensity of this reflection is changing with the angular position of the antenna around the column (trace of antenna: 360°). The reflections at opposite antenna positions (180°) are similar. From this reflection profile it can be concluded, that in the middle of the drum below the joint, a rectangular hole exists (with a length of ca. 7 to 10 cm and a width of 2 to 3 cm) which was used for mounting, see figure 4, top. This hole was only located at the top of each drum and was presumably used for mounting and alignment of the drums. There were no hints to metal compounds as pins between the drums.

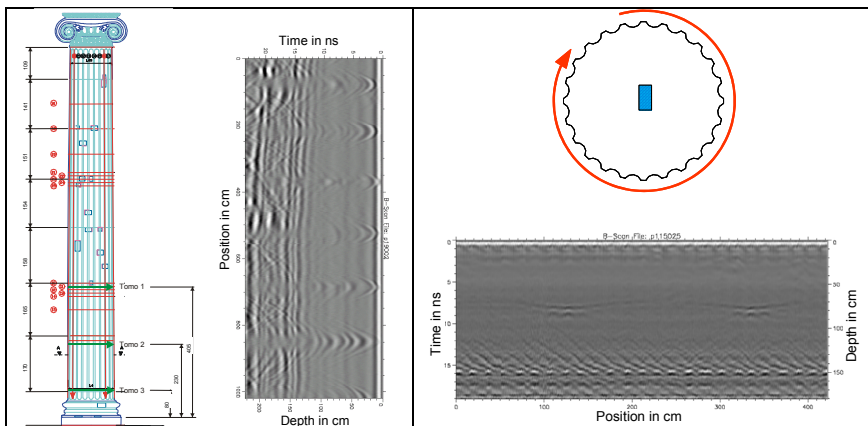


Figure 4: Left: Investigated column (left) and radargram of a vertical trace (right) recorded along the total height of the column with the 900 MHz antenna. The hyperbolas are related to the joints between the drums. Right: Top: Rectangular void in the upper part of each drum used for transportation and alignment. Bottom: Radargram of a horizontal trace recorded with the 1.5 GHz antenna in the upper part of one of the drums.

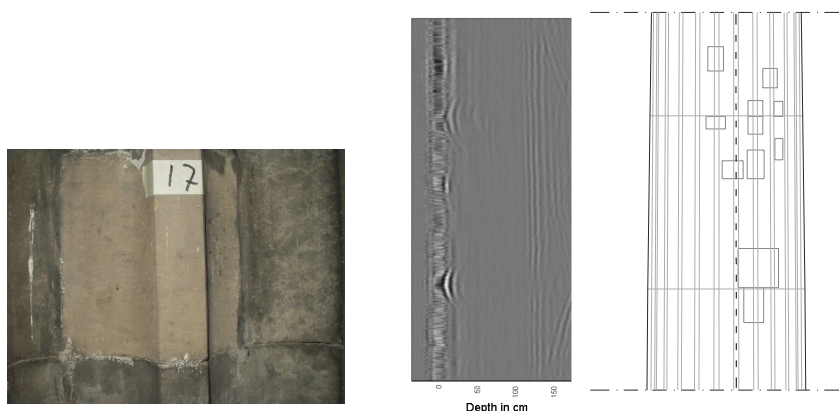


Figure 5: Left: Detail of a repair intervention. Right: Vertical trace across an intervention piece.

Some of the traces intersect positions where repair interventions have been made in the past as shown in figure 5. The radargram shows the result after the removal of the background and the amplification of the signals. This profile crosses two joints, which are indicated by two diffraction hyperbolas in the radargrams as explained above. Additionally, a near-surface signal can also be received from a repaired area crossed by the profile. This means that the repairing material has dielectric properties sufficiently different from the stone of the column so that the radar signal is modified.

In summary, with radar, the joints between the drums could be located very easily, which possibly contain plumb layers between the joints. Related to the connections between the single drums, metal compounds like pins could be most probably excluded. At the top of each column, a rectangular hole is expected which was used for mounting and alignment of the drums. With radar reflection as well as with sonic tomography (not shown here), the repaired areas could be located. But it was not possible to determine the depth of these structures.

3.2 Cupola of the rotunda

For the investigation of the inner structure and construction of the rotunda cupola several measurements have been performed starting from the outer side of the cupola as shown in figure 6. The measuring area had a size of about 2.95 m x 3.00 m and was tested with the 900 MHz and 1.5 GHz antennas.

For the presentation of results one selected radargram performed with the 1.5 GHz antenna (vertical trace) is shown in figure 7. The backside of the cupola is clearly recognisable. The thickness of the cupola varies, depending on the position of the measuring trace (see figure 6 right) above the single waffles. Additionally, reflections (hyperbolas) could be detected close to the surface, which indicate metallic bars and thus probably the anchors.



Figure 6: Left: Photo of the radar measurements at the cupola of the rotunda. Right: Cross section with radar traces of one part of the cupola.

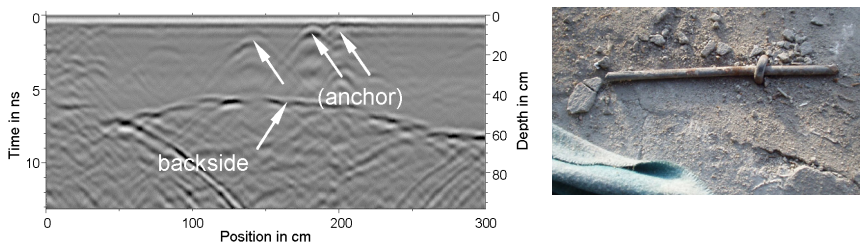


Figure 7: Left: Radargram of a vertical trace at the cupola recorded with the 1.5 GHz antenna. Right: Dissected anchor.

The radar experiment at the sand stone ring was planned in a position of a corridor where the supposed stone ring should be quite close to the internal wall (figure 2, left).

For a more reliable interpretation of the radar images, the experiment was executed in 3D mode by collecting a number of dense parallel profiles on an area of about 80 cm x 80 cm. The data were processed with a 3D software obtaining a 3D data volume that confirms the existence of the stone ring (figure 8). The two reflections observed at about 45 and 80 cm were respectively interpreted as the reflection from the stone ring and from the interface separating the first and the second stone layer of the structure.

Investigations with a videoscope have been carried out to clear up the structure of the sandstone stone ring carrying the dome. At the east side from the exterior wall in the fifth floor, a borehole, which has already been used for former inspections, was opened again and extended in diameter and length. The temporary backfilling of the hole was re-opened. The borehole was then extended to a length of 1.00 m. After the dry drilling operation was completed the hole was cleaned from dust and drilling powder.

The pictures received from the internal faces or areas are recorded with a CCD-chip, which is located at the cone end of the probe, and can be displayed on the video screen and/or be recorded on video-tape. The videoscope can be used

with a cone end for the front view ahead or with an adapter for a view rectangular to the moving direction (angle 90°). The cone end of the probe itself can be moved with a joystick. The inspection process was recorded while the probe was moved around in a 360 °-view every 10 cm.

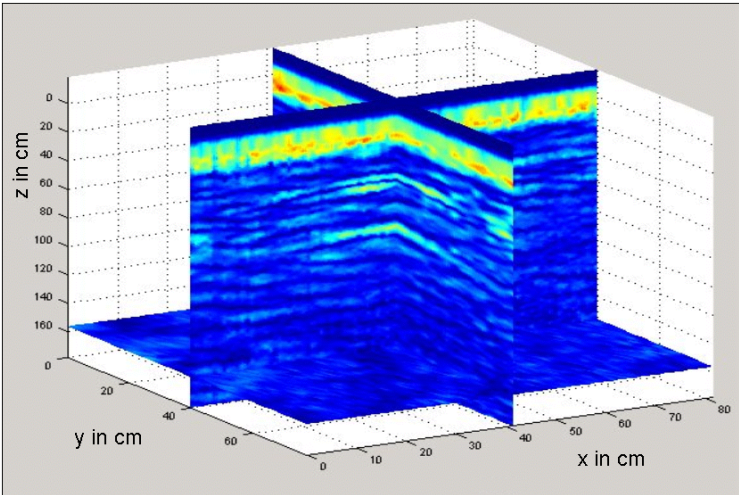


Figure 8: Cross-sections of the 3D radar data showing two main reflections at about 45 and 80 cm.

During the drilling procedure it was noticed that the former drilling penetrated the sandstone ring for almost 11 cm. The superstructure of the wall was determined with the endoscope inspection at this drill hole as described in Table 1. The texture of the sandstone changes in the depth of ca 86 cm as also observed in the radar data. Joints inside the sandstone could not be detected.

Table 1: Material and structures at different depths inside the bore hole at the sand stone ring.

Drilling depth in cm	Material	Notes
0–53	Brickwork	First brick layer with incomplete joints
53–86	Light grey sandstone	Fine-grained, uniform
86–100	Light grey sandstone	Coarse-grained, irregular

3.3 Floor of the rotunda

With radar and impact-echo, the structure and inner condition of selected parts of the floor were investigated. In the following, only the radar results are presented. In figure 9, two radargrams recorded with the 1 GHz (top) and 1.5 GHz antennas (bottom) along a profile that pass over the original and new floor are presented.

Various hyperbolas appear very close to the surface in the new pavement. The occurrence pattern of the diffractions is the following: a hyperbola in the joints (F) and two hyperbolas inside the concrete slabs (B) are representing metallic rebars. Further reflections observed in all radargrams can be related to the bottom side of the floor and the ceiling of the cellar. Due to the complex arch construction of this floor, this back side reflection appears at a different depth. The layered structure of the floor cannot be resolved in any of the radargrams. Thus, the difference of the radargrams recorded in the reconstructed and in the original area is given only through the presence of the reflections from the rebars.

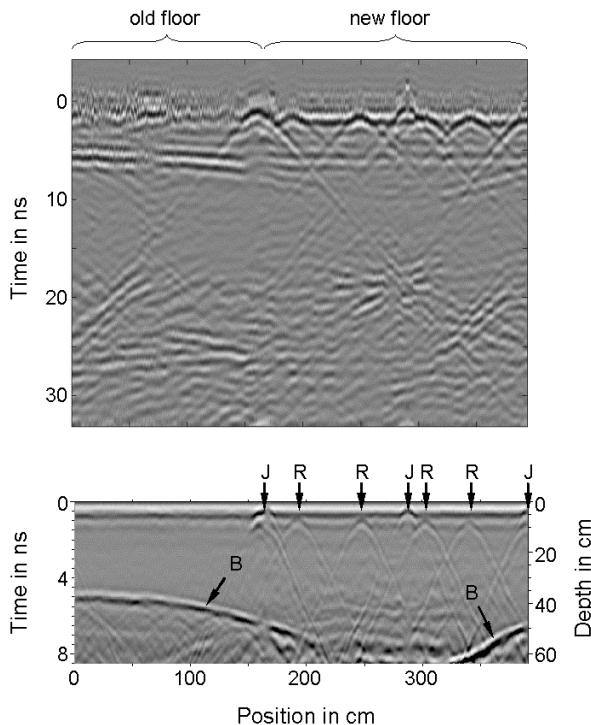


Figure 9: Radargrams recorded with the 1 GHz (top) and 1.5 GHz (bottom) antennas along a trace with original (left) and new (right) floor.

4 Conclusion and outlook

In summary it can be concluded that for the presented historic and constructive questions, radar could be applied very efficiently. Further studies showed that the combination of complementary NDT and MDT methods as well as the combination with conventional testing methods of restorers has a high potential. Promising results came also from the combination with structural modelling (not shown here), which should be considered and enhanced in the future.



As a result of all investigations, it is shown that the interdisciplinary work between building researchers, architects, civil engineers, physicists and restorers is an indispensable need for the performance of successful measurement campaigns with NDT and MDT methods

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