Polarimetric radar signature of masonry walls

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Abstract

A ground-penetrating radar with polarimetric capability has been used for investigating masonry walls. The obtained results show that hollow spaces inside masonry give a well-detectable polarimetric signature that can be usefully used for detecting internal cavities in walls, and for characterizing the masonry.

Keywords: Microwave; Ground-penetrating radar; Masonry

1. Introduction

Penetrating radar imagery offers a unique non-invasive means for retrieving information on the internal structure of masonry and on the localization and size of reinforcement bars, voids and defects [1]. Penetrating radar is used increasingly in the field of Heritage investigation, diagnostics and restoration [2–5].

Recently, full polarimetric ground-penetrating radars have been developed for landmines detection [6–8] and a great number of studies has been performed on polarimetric signatures of mines [7,9,10]. Polarimetric studies aimed at masonry investigation are not known to the authors, in spite of the great interest that enhanced diagnostic tools can have in the field of engineering practice.

This short communication reports an experimental study aimed at investigating the capability of polarimetry as diagnostic tool for inspection of masonry walls.

2. Polarimetric signature of rectangular hollow spaces

Hollow spaces of rectangular shape have internal corners that produce a characteristic polarimetric signature. In fact, let us consider a corner reflector and an electromagnetic wave propagating inside it as in Fig. 1. Because hollow space dielectric constant is smaller than masonry one, reflection coefficient results negative. Every bounce produces a 180° phase shift of the field components. Therefore, a double bounce on a horizontal edge has no effect on the polarity of horizontal polarization (HH), while it produces a 180° phase shift on the vertical polarization (VV) as it can be seen in Fig. 1. In the case of a vertical edge, the VV polarization is back reflected without change, while HH have a 180° phase shift. The polarimetric signature is obtained simply by subtracting the phases of the two measured polarizations (φ(HH)−φ(VV)).

3. Ground-penetrating radar equipment

The ground-penetrating radar used in this study was a laboratory prototype based on a vector network analyzer operating as continuous-wave step-frequency (CW SF) transmitter/receiver, and a couple of bow-tie antennas designed for on-contact operation. The −3dB band of the antennas was [0.5–1.5] GHz. The couple of antennas were arranged in quasi-monostatic configuration, and positioning was performed manually by drawing a suitable grid on the investigated wall. As bow-tie antennas transmit and receive RF waves linearly polarized along the direction of the dipole, HH and VV measurements are obtained simply by rotating the antennas of 90°.
The VNA transmitted a sweep of monochromatic tones from 0.5 to 1.5 GHz at steps of 5 MHz, and for each tone the VNA acquired the in-phase and quadrature signals. The transmitted power was 20 dBm. The working principle of a CWSF radar is based on frequency domain sampling [5]. The signal in time domain can be obtained simply by calculating the inverse FFT of the acquired signals. It is of interest to note that CWSF operation is not an essential requirement for applying the technique reported in this work, that can be extended to a generic coherent radar.

4. Experimental results

Two investigations were performed on masonry test facilities built at the Laboratories of the University of Florence, Italy. Data set has been post-processed with a focusing algorithm based on a migration technique [11]. In order to apply successfully the focusing technique, the acquisition has been performed on a planar grid with steps shorter than a quarter of a wavelength.

The first experiment has been carried out on masonry test facility that consists of three walls as shown in Fig. 2. The first one is a wall 12 cm thick of full bricks and lime. The second is built with full bricks without lime and has a hidden cavity of dimensions [50 × 20 × 12] cm. The third wall is a concrete structure 50 cm thick. The radar was operating at contact with the first wall.

Fig. 3 shows the images of a slice at approximately 15 cm depth. Figs. 3a and b show, respectively, the amplitude maps in horizontal (\(|HH|\)) and vertical (\(|VV|\)) polarization. Polarimetric phase map (Fig. 3c) is obtained by subtracting the two focused phase maps, \(\phi(HH) - \phi(VV)\). Although the cavity is visible in amplitude maps (Figs. 3a, b), its edges are significantly clearer in the polarimetric phase image.

The second test has been performed on a masonry of hollow bricks shown in Fig. 4. A grid structure that reproduces the mortar between the bricks can be recognized also in amplitude maps in Figs. 5a (\(|HH|\)) and b (\(|VV|\)), but the polarimetric phase map (\(\phi(HH) - \phi(VV)\)) in Fig. 5c is even clearer: inner edges of hollow bricks are clearly visible, and their phase values (±180°) is coherent with the theory of the double bounce on the corners. It is interesting to note that in radar images the brick pattern is
Fig. 3. Radar images at 15 cm depth of the brick masonry with a rectangular internal cavity. (a) HH amplitude image, (b) VV amplitude image and (c) HH–VV polarimetric image.
less evident near $x = 1.6$ m where the second wall, perpendicular to the first one, troubles the regular structure of bricks.

5. Conclusion

The reported tests have shown the ability of the proposed polarimetric technique to detect hidden cavities and hollow spaces in masonry wall, by evidencing the phase rotation at the edges due to the double-bounce reflection on the corners. This technique can provide an useful complementary information enhancing the diagnostic power of the ground penetrating radars designed for masonry investigation.

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References