Subsurface Radar for Non-Destructive Testing for Structures of Buildings

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Abstract
Radar polarimetry is a technique which can provide rich information of targets, under the restricted radar imaging resolution. In applications of subsurface radar to NDT for material and structures of buildings and constructions, electromagnetic wave penetration into the material and the radar resolution are conflicting issues. In order to achieve deep penetration, we have to use lower frequency, and it will limit the frequency bandwidth, and consequently, we cannot achieve high radar resolution. However, if we could use polarimetric information extracted by radar measurement, we can know the surface roughness, and other complicated structural information of the targets. In this case, we do not have to know the shape of the structure, but we can know the very detailed properties of structure by relating to the polarimetric scattering. In this paper, we will show a few examples which use radar polarimetry for NDT. We demonstrate how the inner structure of concrete and wooden buildings can be visualized by subsurface radar. Deformation of material less than 1mm can be detected by this method. Then we will demonstrate the imaging by using a prototype radar which operates at 10-20GHz. This radar will be used for NDT of wooden houses by the earthquake and tsunami affected area in East Japan on March 11, 2011.

Keywords: Subsurface Radar, GPR, Radar Polarimetry, Wooden Structures

1. Introduction

Most of the Japanese private houses are built by wood. After the Great East Japan earthquake and tsunami in 2011, we recognized that many of the wooden houses keep the original shape after the strong earthquake, because the wooden structure is very elastic. However, we cannot know whether these houses were structurally damaged or sound. For example, in the Onagawa town, Tsunami reached at 25m above the sea level, and most of the houses below 25m were completely flashed away. However, most of the houses above the 25m are still look fine. However, we cannot inspect the damage or deformation of wooden structures such as pillars inside the wall, because observation from outside the wall cannot detect these defects.

The ministry of internal affairs and communication of Japan initiated an intensive research project to develop the NDT methodologies for evaluation of the damage of wooden houses after the East Japan earthquake and tsunami in 2011. Tohoku University and Mitsui Engineering and Shipbuilding Co. Ltd started collaborative research to realize radar technology for NDT applied to wooden structures [1][2]. In order to achieve the higher resolution, we use SAR (Synthetic Aperture Radar) algorithm for image reconstruction. Higher frequencies are preferred to detect small defects in walls, because we can have a larger frequency bandwidth; however, a large part of energy at higher frequencies is reflected at the surface and/or is attenuated in the material. To overcome this problem, we are investigating the use of radar polarimetry. Radar polarimetry has been validated to bring detailed information on targets in remote sensing, but still not widely used in subsurface radar.

In this paper, we introduce the results of laboratory radar tests by radar system using frequency up to 20GHz, and then we sow some results of the feasibility study by using a prototype liner array GPR operating at 10-20GHz. We also demonstrate that radar polarimetry can be useful for these purposes.
2. GB-SAR System

We constructed a polarimetric radar system based on a vector network analyser (VNA) for this study. Transmitting and receiving antennas are connected to the VNA to consist a radar system. VNA is used for transmitter and receiver, because the system is very flexible, and the operation frequency can be selected. The transmitting and receiving antennas are moved by antenna positioner, and after acquiring radar data, we use Synthetic Aperture Radar (SAR) processing, which is equivalent to the migration, for the radar image construction, SAR is commonly used for data acquired by radar system on spacecraft, but our system is based on a fixed antenna positioner. Therefore we call it Ground Base SAR (GB-SAR)[3][4].

3. Application to Model Structures

3.1 Concrete structure

The GB-SAR system was evaluated at first by applying to a concrete specimen, which simulates one span of a concrete wall structure. The specimen used for this test was artificially pressed and deformed, which caused apparent fracture inside and outside the concrete structure [5]. We demonstrated that we can emphasize the specific featured of inner structure by changing the polarization of the transmitting and receiving waves, and we use these phenomena to detect some specific targets from radar images, which are known as polarization optimization or polarization filtering method. We think concrete surface, rebars and cracks inside concrete structure could be separated by this polarization filtering.

3.2 Wooden structure

Many of private houses in Japan are made of wood. The strength of wooden houses against strong shake by earthquake is determined by the size and numbers of wooden pillars and structure of the wall connecting the wooden structures. Due to the improvement of the regulation in 1981 and 1995, the structure is more resilient against the shake by earthquakes. Fig.1 shows the one span of a wall of a typical wooden house, which will be used for evaluation of subsurface radar investigation. These wall structures were constructed under the regulation after 1995. Note that due to the limitation of the height of the room, the wooden specimen is rotated by 90 degree. We made 2 identical specimens for 2 types, and one of the specimens was deformed by pressing by jack and the inner structure was damaged. We cannot find the damage from outside as seen in Fig.1
Radar data was acquired by using Vivaldi antennas for these wooden structures. Fig.2 shows the reconstructed radar image by SAR processing. We can understand that the SAR processing clearly shows the structure of the target, and suppress the diffracted radar signal. In addition, we can find this high resolution shape of the metal objects such as the head of nails in Fig.2(b). We think that the detection of the deformed metal objects used for joining the wooden structure can be a good indication of damage to the structure.

Figure 2. Reconstructed image of inner structure of wooden wall model by SAR processing

In addition to the real scale model testing, we show some small-scale demonstration test results. We demonstrated the capability of detection of small deformation of wooden structure by using radar polarimetry [2]. 2 wooden bars having flats surface are placed on a plane, with small inclined angle to imitate the deformation caused by strong pressure on the wooden bar. Figs.3 shows the phase differences between different polarization images. In these figures, we can clearly find the deformation of the surface of a wooden beam. The deformation is only a few mm, and which is equivalent or smaller than the radar range resolution. We can easily find the deformed wooden beam.

Figure 3. Radar polarimetric image showing the slight deformation of wooden bar

4. Prototype Radar System

In this research project, we are developing a proto-type radar system, in order to validate the research results tested in the laboratory. Mitsui Engineering and shipbuilding co. Ltd, is
working together and built the 10-20GHz linear array subsurface radar system [6]. 32 pairs of Transmitting and receiving antennas are linearly aligned in the system. By evaluation of the system in laboratory, we could demonstrate that wooden bars with bended angle can be imaged. This system is now tested in real situation.

5. Conclusion

We have developed a wide-frequency band full polarimetric subsurface radar system, which operates at 1-20GHz. We have demonstrated some measured results. For a concrete structure we found that by polarization optimization, we can separate the images of concrete surface, rebars and cracks inside the concrete structure. For the measurement of a wooden wall model, we demonstrated that we can image small metal parts inside the structure, which will be useful information for understanding the history of the damage, and also showed that radar polarimetry can detect small deformation of wooden structure which is less than 5mm. We have developed a prototype radar system operating at 10-20GHz and using this system, we are continuing feasibility study for real inspection of wooden houses.

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