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ODREĐIVANJE MOGUĆNOSTI GEORADARA U OCJENI STANJA KONSTRUKCIJA

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Sažetak

Ocjena stanja konstrukcija nerazornom metodom georadar (GPR) temelji se na analizi jakosti, predznaka i oblika reflektiranog signala od objekte ispod ispitivane površine. Stoga se koristi za lociranje armature u armiranobetonskim konstrukcijama, određivanje vrste i strukture konstruktivnih elemenata, ocjenu korozije armature, itd. U ovom radu prikazana je primjenjivost georadara za lociranje armature i određivanje geometrije konstruktivnih elemenata, kao i studija o osjetljivosti signala georadara na parametre korozije izazvane kloridima.
Ključne riječi: georadar, beton, ocjena stanja, korozija

IDENTIFYING THE CAPITABILITIES OF GROUND PENETRATING RADAR IN STRUCTURAL CONDITION ASSESSMENT

Abstract

The condition assessment of structures using the non-destructive ground penetrating radar (GPR) method is based on the analysis of the strength, sign and shape of the signal reflected from the objects under the examined surface. Therefore, it is used for locating reinforcement in reinforced concrete structures, determining the type and structure of structural elements, evaluating the corrosion of reinforcement, etc. This paper presents the applicability of the GPR method for locating reinforcement and determining the geometry of structural elements, as well as the study of the sensitivity of the GPR signal to chloride-induced corrosion parameters.
Keywords: ground penetrating radar, concrete, condition assessment, corrosion

1. Introduction

After the earthquake that struck Zagreb in March 2020, an estimated 25,000 buildings were affected by this natural disaster. Buildings constructed before the implementation of modern seismic regulations [1] were particularly vulnerable to damage. According to [2], more than 85% of buildings in Zagreb's Downtown were built more than 50 years ago. In addition to the magnitude of seismic activity, the lack of regular maintenance of these aged buildings significantly contributed to the extent of damage. Such disasters highlighted the importance of regular and thorough inspection. The use of non-destructive techniques is highly desirable, especially for historically significant listed buildings [3–6].

In the last two decades, one of the most commonly used non-destructive techniques has been ground penetrating radar (GPR). GPR is based on the emission and detection of electromagnetic waves [7, 8] reflected from layers, edges or objects in structural elements. The technique is mainly used in reinforced concrete structures, although, with increasing knowledge and experience, GPR is also used in the inspection of structures made of other materials [9, 10].

This paper presents examples, results, and conclusions from research conducted as part of ASAP [11], a four-year project to develop a robotic system equipped with GPR for the inspection of structures.

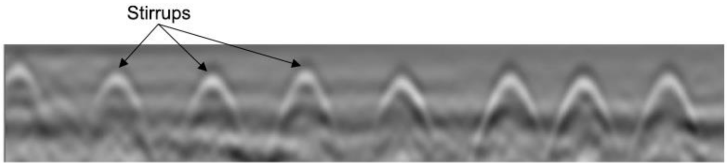
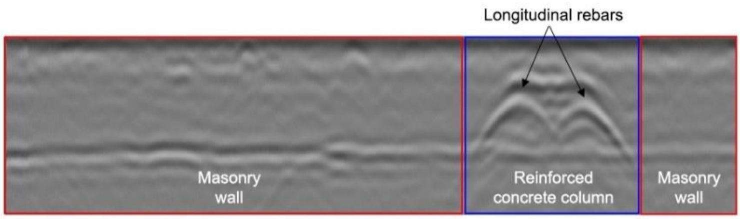
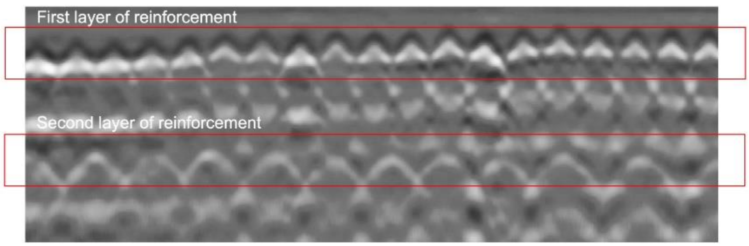
2. Application of GPR in the structural assessment

2.1. Reinforcement in concrete structures

One of the most common applications of GPR in the condition assessment of concrete structures is the derivation of information about the location of reinforcement in structural elements. The analysis is based on the detection of reflections from the top of the reinforcing bars, which determine their position and the distance between them. The GPR used in the inspection of structures is usually a hand-held device on wheels, where the encoder measures the distances in the inspection direction. In order to determine the depth of the reinforcing bars, the correlation between the time the wave passes through the concrete and the speed of the wave must be established. On the other hand, the wave velocity depends on the dielectric permittivity of the concrete, which can be measured by other techniques, estimated from literature values [12] or derived from the GPR measurement of an object with known depth.

The examples of radargrams obtained in the GPR determination of reinforcement location are given in Table 1. It should be mentioned that the direction of the radargram is perpendicular to the direction of the rebar of interest.

Table 1. The specific radargrams of the reinforcement investigations in concrete structures.

	Radargram
Stirrups in reinforced concrete column	
Longitudinal rebars of reinforced concrete column in masonry wall	
Two reinforcement layers in reinforced concrete slab	

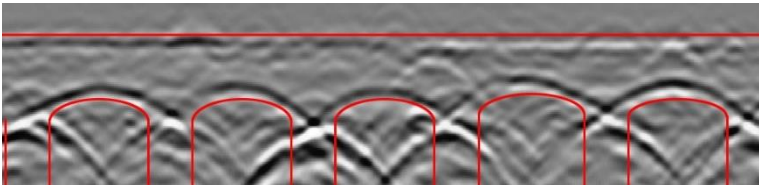
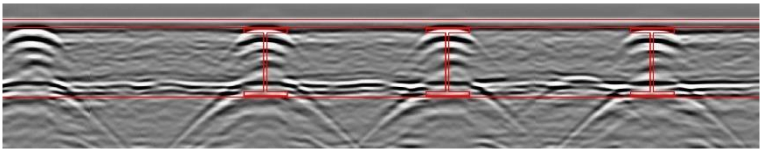
The advantages of GPR over other non-destructive methods for determining the position of reinforcement in reinforced concrete structures are its relatively high accuracy at large penetration depths (up to 60 cm) and the simultaneous investigation of other properties of the element, e.g., concrete cover and element thickness and composition of the structural element. Disadvantages include advanced signal processing in certain cases, knowledge of the principles of electromagnetic theory and inaccurate results in the case of congested objects.

2.2. Geometry of structural elements

Aside from the position of reinforcement in concrete structures, the GPR could be used to determine the geometry of structural elements. The geometry is analyzed based on the strength, phase, and travel time of reflected waves. Examples of radargrams are given in Table 2.

The limitations of using GPR to determine the geometry of structural elements lie in the complicated geometry with many reflections from different objects and materials. In addition, as the depth of the element increases, the analysis becomes more complicated as the reflection of the object begins to disappear. Some of the problems mentioned could be overcome with additional signal processing.

Table 2. The specific radargrams from the geometry investigations of structural elements.

	Radargram
Curved bottom edge of ribbed slab	
Arrangement of metal beams in the mezzanine slab	

2.3. Corrosion of reinforcement

One of the most difficult but potentially very valuable tasks is the evaluation of the corrosion of reinforcement in reinforced concrete structures based on the GPR signal. The analysis is based on observing the change in signal amplitude as a result of the change in concrete and reinforcement due to the corrosion process. The change in the signal can be roughly divided into 1) changes due to material changes and 2) changes on the reinforcement surface. The former is related to the changes in the dielectric permittivity, electrical conductivity, and magnetic permeability of concrete as a material. The agents responsible for certain types of corrosion, such as moisture and chlorides, as well as corrosion products, e.g., rust, change the material properties, which in turn change the signal strength. The second reason is the change in the reflection coefficient, as the reflective surface changes due to the accumulation of corrosion products on the top of the reinforcement.

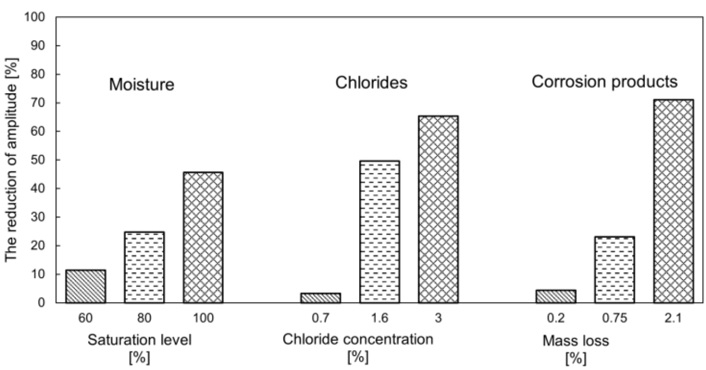


Figure 1. Comparison of the effect of corrosion-related attributes on GPR amplitude.

The comparison of the effects of moisture, chlorides, and corrosion products on the change in GPR signal amplitude is shown in Figure 1. These are the results of the laboratory study on reinforced concrete specimens where the rebar was embedded in the concrete 5 cm from the inspected surface. On the left side of the diagram, the effect of increasing the saturation level from 50% to 60%, 80% and 100% on the signal amplitude is shown. The middle of the diagram shows the effect of increasing the mean chloride concentration in the concrete cover to 0.7, 1.6 and 3% of the cement mass at a fixed saturation level of 80%. The right side of the graph shows the effect of 0.2%, 0.75% and 2.1% mass loss of reinforcement due to corrosion, without chlorides, under ambient laboratory conditions.

Any increase in the observed effect, i.e., an increase in the degree of saturation, chloride concentration, or accumulation of corrosion products, results in a decrease in amplitude. The increase in the degree of saturation in concrete leads to dipolar polarization effects [13], which are associated with a loss of amplitude due to the rotation of water molecules in the electromagnetic field. The increase in chloride concentration increases the conductivity of the concrete [14], resulting in amplitude loss due to the collision of the dissolved ions in the pore water in the presence of the emitted electromagnetic signal. The corrosion products migrating into the concrete pores change the magnetic permeability [15], which further enhances the amplitude reduction.

The analysis of the corrosion state by means of GPR becomes very demanding when all the above parameters change the GPR amplitude simultaneously.

3. Conclusion

This paper presents the results of the research carried out within the project ASAP on the application of ground penetrating radar for the condition assessment of structures. GPR is a very valuable non-destructive technique due to its wide range of applications in the inspection of structures. However, apart from its main purpose of locating metallic objects below the surface, the analysis of the results in other cases is challenging and requires knowledge of signal processing and electromagnetic theory.

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