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Editorial

Non-Destructive Testing in Civil Engineering

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1. Introduction

The progressive development of civil engineering has forced scientists to improve the known methods and techniques of testing building materials, and also to search for new ones, e.g., non-destructive testing (NDT) methods. These methods usually do not interfere with the tested material and structures during tests. Despite this, NDT methods not only allow for the assessment of many important material properties and parameters, but also for the reliable localization of imperfections, damage, or internal defects in tested elements and structures. This knowledge is needed in many situations in order to e.g., correctly assess operational safety, reliability, durability, and the degree of degradation. It is worth noting that there has recently been significant progress in the development of NDT methods, especially those from the group of acoustic methods. These methods, as is the case in medicine, are very useful for obtaining information about the examined structures and the inside of elements on the basis of recorded acoustic signals. These signals are then processed by appropriate software with the use of complex data analysis, including artificial intelligence.

This Special Issue, entitled "Non-Destructive Testing in Civil Engineering", aims to present to interested researchers and engineers the latest achievements in the field of new research methods, and also the original results of scientific research carried out with their use-not only in laboratory conditions, but also in selected case studies. The articles published in this issue are theoretical-experimental and experimental, and also show the practical nature of the research. They are grouped by topic, and the main content of each article is briefly discussed for your convenience.

These articles extend knowledge in the field of non-destructive testing in civil engineering with regards to new and improved NDT methods, their complementary application, and also the analysis of their results-including the use of sophisticated mathematical algorithms and artificial intelligence, as well as the diagnostics of materials, components, structures, entire buildings, and interesting case studies.

2. Research in the Field of New and Improved Methods and Techniques of Non-Destructive Testing

Ref. [1] presents an experimental method of measuring small forces between the fluid and a wall in open water channels using a strain gauge as a force sensor. For this purpose, six uniaxial strain gauges were used, which were placed throughout the measurement area and subjected to bending tests in order to determine the correlation between the load and the obtained signal. A special data acquisition system was established to record the performance of the strain gauge in relation to the lateral displacement caused by the testing machine. The obtained results indicated a linear relationship between the load and the obtained signal for the situation when the strain gauge was seated in the zone from 30% to 45% from the central axis in the sensor's measuring region. The described sensor can therefore be used to measure small magnitude forces. Additionally, the linear correlation between the load and the obtained signal can be used for calibration, as long as the strain gauge is seated close to the central axis of the detection area.

In turn, article [2] is devoted to the identification of cracks in concrete. The work associated with this kind of research requires effort and equipment, such as articulated ladders. Additionally, there are important health and safety issues, as some structures are not very accessible. To deal with these problems, various studies have used digital imaging to measure cracks in concrete. The purpose of this experimental study is to evaluate the optical limit of digital camera lenses with regard to an increased working distance. Three different lenses and two digital cameras were used to record line images with a thickness of 0.1 to 0.5 mm. Field measurement tests were carried out to verify the measurement parameters identified on the basis of the results of the performed research. The actual crack widths were visually measured, and the obtained values were used for further analysis. Based on the conducted studies, it was confirmed that the number of pixels that corresponds to the working distance had a large impact on the accuracy of the crack width measurement when using image processing. Therefore, the optimal distance and measurement guidelines required to measure the size of some objects were provided for the imaging and optical equipment that was used in this study.

In conventional thermography, a sample is subjected to a periodically changing stream of heat. This heat flux usually enters the sample in one of three ways: by a point source, a line source, or an extended source. Calculations that were conducted on the basis of surface sources are particularly well suited to solar load thermography. This is due to the fact that most natural heat sources and heat sinks can be brought closer in order to be uniformly extended over a certain area of interest. This is especially interesting because the natural thermal phenomena cover large areas, which in turn makes this method suitable for the measurement of large-scale samples. Article [3] describes an investigation of how extended approximation source formulas for determining the properties of thermally thick and thermally thin materials can be used in a naturally excited system. This work also shows the possible sources of errors, and gives quantitative results to estimate the thermal efficiency of a retaining wall structure. It was shown that this method can be used in the case of large-size structures that are subjected to the natural phenomenon of external heating.

Progress in the impact-echo (IE) method is due to the automation of the scanning of concrete bridge decks. The toothed system that was presented in [4] when describing the IE method was developed using gears as impacts and microelectromechanical systems. This system continuously collects a large amount of field test data because a rack generates impacts automatically. The duration of the contact between two gears is assessed, and the contact mechanism is then compared to a steel ball mallet using a high-speed camera. Data were collected based on the measurements of concrete slabs in which artificial voids were embedded at different depths. Based on the experiments, a reduction in pitch, or an increase in the number of teeth, was required to reduce the contact time and to generate the thickness frequency from deep delaminations. Automatically acquired time-domain data was shifted to the frequency-time domain by means of spectrograms in order to identify the dominant frequency of a set of obtained signals. The results display that the developed method enabled to obtain high-quality data during IE tests. In turn, the spectrogram analysis delivered important information about the frequency of the obtained IE signals, and verified the repeatability of the data.

The aim of the article [5] was to analyze the most modern techniques of measuring electrical impedance (and consequently electrical resistance) of mortar/concrete elements. Various measurement methods are described and discussed, with the advantages and disadvantages with regard to their performance, reliability, and degree of maturity being highlighted. The usefulness of electrical resistivity measurements was demonstrated. Due to the fact that electrical resistivity is an important indicator of the health of concrete, and also that it changes whenever there are phenomena modifying the conductivity of the mortar/concrete (e.g., degradation or external influences), the conducted review of measurement techniques was meant to serve as a guide for those interested in these types of measurements.

3. Complementary Applications of the Non-Destructive Testing Methods

Article [6] presents resonance frequency tests of bent concrete samples. These frequencies were determined simultaneously using the sonic resonance method and the impulse excitation technique, with the two methods then being compared. The samples differ in used material and shape. The mean values and corresponding values of standard deviations of the resonance frequencies were compared. The performed tests showed the equivalence of both methods of measuring the resonance frequency. The obtained difference between the values measured using the sonic resonance method and the impulse excitation technique were not significant. The relationship between the resonant frequencies, which is presented graphically, is linear with a slope of 0.9993.

Fibrous reinforcement in high-performance cement materials is widely applied in many areas of the construction industry. One of the most frequently studied features of steel fiber reinforced concrete is the slower development of cracks, which in turn results in the better durability of such concrete. Additional benefits are related to structural properties, as fibers can significantly increase the ductility and tensile strength of concrete. In some applications, it is even possible to completely replace conventional reinforcement with fiber reinforcement, leading to significant logistical and environmental benefits. However, it can have disadvantages, as the fibers can induce anisotropic behavior of the concrete if they are not properly oriented. For the safe use of steel fiber reinforced concrete, non-destructive testing (NDT) methods should be used in order to assess the orientation of the fibers in the hardened concrete. For this purpose, article [7] uses complementary methods of ultrasound, electrical impedance and X-ray computed tomography. The article also demonstrates the capabilities of each of these techniques separately when measuring fiber orientation. Based on these results, conclusions were drawn regarding the most promising areas for future research and development.

Article [8] examines the use of a heat flux meter and quantitative infrared thermography to assess the difference between the predicted and real thermal conductivity of house facades under steady-state conditions in the Mediterranean basin. First, the suitability of NDT techniques was tested experimentally, and then a single-family house was verified in a real environment. The outcomes of this study show that both techniques quantified the difference between the design and real U-value of a house facade. The quantitative infrared thermography method was faster than the heat flux meter method, although the flux meter method has higher accuracy. The presented results will help when choosing the most appropriate test method.

4. Analysis of the Results of Non-Destructive Testing, Including the Use of Sophisticated Mathematical Algorithms and Artificial Intelligence

Until now, the analysis of cores obtained from a structure by drilling is the main option to obtain knowledge about the depth of damage due to water penetrating the floors of buildings. The time-consuming and costly procedure is an additional burden for building insurers, who mention water damage caused by leaking pipelines as the most common claim against insurers. The radar method, due to its high sensitivity to water, can be an important and non-destructive support for this problem. Therefore, the article [9] describes a modular sample, which was developed to obtain the appropriate thickness of screed and insulation material. The resulting dataset was then used to examine the corresponding characteristics of a signal in order to classify three situations: dry insulation, damaged insulation, and damaged screed. It was highlighted that the analysis of the statistical distributions of the scans allows for an accurate identification of damage on floors. Combining the proposed functions with multidimensional data analysis and artificial intelligence was crucial to achieving satisfactory results.

Article [10] shows a numerical analysis of the application of the ultrasonic method for the detection of underground voids in the ground in order to check the properties of the underwater seabed period. The obtained numerical model demonstrates the possibility of detecting (with a spatial resolution of about 0.5 λ) subterranean void airspace. The proposed technique can overcome the limitations of conventional techniques, which use sonar devices that are characterized by a low penetration depth and the leakage of the transverse sound wave propagating in the underground fluid environment.

Article [11] presents the results of the verification of a method of assessing the moisture content of saline brick walls based on non-destructive measurements and artificial intelligence. The method was formerly developed and can be suitable for the non-destructive identification of the moisture content of walls in historic buildings when destructive interference during the research is not possible because of the conservation limitations. However, before its implementation into construction practice, this method requires validation of other historic buildings. The results of testing the dampness of two selected historical objects were used for the experimental verification of the model obtained by the artificial neural network (ANN). These results were different than those used for learning and testing the ANN. The obtained high values of the linear correlation coefficient and low values of mean absolute error confirm that the obtained ANN model is useful in assessing the moisture content of saline brick walls.

5. Diagnostics of Materials, Elements, and Structures, as well as Entire Buildings

The study presented in [12] aims to propose a list of defects that can be found in several types of building elements/materials, which will in turn simplify issues related to the diagnosis of building pathologies. The database was formulated with the use of previously developed elements of the global control system: a fault classification list and the urgency of repairs. This database has been structured using tables ordered according to defect type, building component/material, and urgency to repair (a five-point scale of 0–4). The repair urgency levels are demonstrated with photos and described using brief criteria. Not all the repair urgency levels are applicable to all the combinations of "defect-component/material". Levels 1, 2, and 3 are most frequently taken into account. The proposed list of defects is a novel approach that can be useful to support experts during inspections of buildings, the concept of which can be adapted to further inspection systems.

The aim of the article [13] was to present the influence of temperature and humidity on the mechanical properties of a conveyor belt. The investigations were carried out in both a climatic chamber, which simulates the effects of negative and positive temperatures of −30 °C to 80 °C (243 K to 353 K), and in a thermal shock chamber. The results of the tests in the climatic chamber showed that numerous mechanical parameters have undesirable values at 10 °C (283 K) and 80 °C (353 K) at a relative humidity of 80%. Interestingly, the results showed that the tensile modulus, tensile strength, and yield point are higher at temperatures below 0 °C than at temperatures above 0 °C.

6. Interesting Case Studies in the Field of Non-Destructive Testing in Civil Engineering

In article [14], it was shown that active thermography methods, such as step heating thermography, show a good correlation with the solar load system. Solar load thermography is an approach that has recently gained the attention of scientists. It is beneficial because it is particularly easy to set up and can measure objects on a large scale due to the fact that the sun is the main source of heat. This work also introduces the concept of using a pyranometer as a reference point for evaluation algorithms by providing a direct measurement of the intensity of solar radiation. In addition, a recently introduced method of estimating thermal efficiency is assessed using thermograms of the environment.

Article [15] presents the portable X-ray sources that were developed in the last 10 years and which are based on a linear electron accelerator with a power of 950 keV/3.95 MeV in the X band (9.3 GHz). Moreover, it also describes the inspections of prestressed concrete bridges. A bridge with a T-shaped PC girder, 200–400 mm thick, and a bridge with a box-shaped PC girder, 200–800 mm thick were subjected to tests. X-ray images of the defects of the tendon ducts were observed. An attempt to quantify unfilled mortar was made. This is due to the fact that this is the major defect that causes corrosion. On the taken X-ray images, gray values were obtained, which correspond to the X-ray attenuation coefficients of filled and unfilled mortars in tendon ducts. The gray ratio of the filled/unfilled tendon ducts was then compared in order to determine the degree of filling. For this purpose, data obtained from an actual T-shaped post-tensioned concrete bridge and model samples were used to validate the method.

Precise evidence of the thermal conductivity of walls is essential for selecting the proper energy-saving measures in existing buildings. For reliable testing using the heat meter method (HFM), good thermal contact should be provided between the heat meter plate and the surface of the wall. The aim of the article [16] was to assess the effect of an imperfect thermal contact of the heat meter plates on the accuracy of the in-situ measurements of the U value of the facade after applying foil. The foil was applied in order to avoid damage to the surface of the wall, which is a normal procedure during the operational phase of a building. The results show that the deviations between the measured U-values and the values obtained using the HFM directly on the wall surface and when HFM was installed with a PVC film were significantly different from the theoretical values.

Article [17] concerned the application of geophysical techniques in the urban environment of the city of Nicosia in Cyprus. The main goal of the research, being part of the Eleftheria Square redesign project, was to visualize subsurface properties in order to reduce the impact of threats on old buildings (and thus to preserve the cultural heritage of the site) and new infrastructure under construction. Since 2008, various phases of the project have used electrofusion tomography, radar, and also electromagnetic induction methods to provide an understanding of the geological stratigraphy of buried objects (archaeological and underground structures) and unexpected events (such as water infiltration). The results of geophysical research confirmed the effectiveness of the adopted methods, and added cognitive value with regard to the studied area. The new information gathered helped public administration technicians to plan direct and targeted interventions and to modify the original design in line with the discovery of archaeological finds.

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