Assessment of the technical condition of concrete bridges by means of infrared thermography

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Abstract. The aim of the article is to analyze the applicability of infrared thermography as a diagnostic tool to support the inspections of the structure and equipment elements of bridges. Infrared thermography consists of recording the power of electromagnetic radiation emitted by the surface of a given body. Thanks to the IR camera, the energy of the infrared radiation is converted into an electrical signal whose value depends on the temperature of the object. The starting point is the assumption that the distribution of temperature anomalies, recorded by IR camera, may be associated with located under the surface hidden defects. In-situ and laboratory tests were performed to document the use of this NDT tool in bridge diagnostics.

1. Introduction
Standard procedures for carrying out bridge inspection, i.e. assessment of its technical condition and suitability for use, are based on a visual observation performed by a bridge inspector. Depending on his professional experience, the final rating is arbitrarily formulated. This process is formalized in order to simplify and shorten site inspections and therefore not always fully objective. For typical bridge structures, which have no structural defects and are systematically maintained, current and basic inspections are a satisfactory way of assessing them. Due to the fact that a large part of the bridges in Poland has been operated for many years and their technical condition is unsatisfactory, there is a need to implement new measurement techniques that would help improve the road administration decision-making processes related to bridge maintenance and repair.

According to reports [4,6,7] made by academic centres at the request of government road administration authorities in Missouri and Washington, it can be concluded that works on the implementation of infrared thermography for bridge inspection are quite advanced. The above mentioned reports present an important role of preliminary laboratory tests, which are used for qualitative evaluation of heat flow phenomena, the manner of implementation of thermal forces and the method of conducting measurements taking into account various external factors. At the same time, it stresses the need for appropriate training of users, who must have the necessary knowledge to interpret measurement results.

The publication [8] describes the results of analyses of possible use of 12 non-contact measuring techniques (methods) treated as a tool supporting the evaluation of selected bridge elements. The

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following aspects of individual methods were analyzed: applicability in field conditions, measurement accuracy, test time, cost of the measuring devices, and ease of interpretation and usefulness of measurement results.

One of the first applications of infrared thermography for bridges can be found in the article [2], where the state of moisture in the surface of a single-span arch stone bridge was analyzed using a thermal imaging camera. Thanks to better technical parameters (geometric resolution and thermal sensitivity, as well as handyness), modern thermal imaging equipment is also used to test the technical condition of the bridge's supporting elements. Such an example of the application of thermography in the context of the global analysis of the state of brick arch bridge from the first half of the 19th century located in Venice is the work [1]. This article presents the results of research from the review of the bridge made with the use of three in-situ techniques: geo-radar, thermographic and dynamic excitation, extended and supplemented with numerical analysis. The combination of two non-destructive methods (impact-echo and IRT) for the analysis of various "artificial" damage to a full-scale section of the reinforced concrete deck is presented in an article [3]. This article is a continuation and extension of research carried out by authors [5] and presented at the QIRT2016 Conference.

2. Survey methodology of the bridge object
The main aim of this research is to try to answer the question whether infrared thermography can effectively improve the detection and identification of defects in concrete bridges. In our opinion, this method could be used to initially diagnose the technical condition of the object and would complement the classic bridge inspections. In the case of concrete structures, the most common damages are internal voids (so-called crayfish), delaminations of concrete coverings layer due to corrosion of reinforcement, chemical corrosion of concrete, occurrence of cracks and areas of poorly compacted concrete mix, dampness, inclusions of other materials, etc.

The methodology for testing a bridge object with an IR camera should take into account the following steps:

- knowledge of the technical documentation of the object (sometimes unavailable)
- determination of the range and sequence of infrared camera tests
- continuous thermal imaging measurements (from road and ground level) to detect potentially dangerous areas and preliminary analysis of results
- selection of areas for more detailed measurements (e.g. using a tripod, elevator, scaffolding, etc.)
- if necessary, the use of devices for thermal stimulation of selected areas (e. g. radiation emitters)
- analysis of the obtained thermograms using standard software or specialized mathematical tools
- formulating the final conclusions.

Literature studies and own experience show that field tests should be preceded by experiments on a laboratory scale, which makes it easier to get used to the apparatus, its capabilities and limitations in detecting hidden defects. In the case of prototype research, strong, domain oriented, numerical analyses are helpful in qualitative evaluation.

3. In-situ tests
The results of own tests carried out for two different concrete objects located in Poznan are described below. In the future, analogous tests are planned to be carried out in relation to structures with a steel supporting structure. Measurements were taken from the ground level.

The first of the bridges is a continuous, three-span frame structure (27.0+36.0+27.0m), built in 1970. The structure of the bridge bay in cross-section is a compressed concrete slab with holes, which are made of Spiro pipes with a diameter of probably 600 mm. Concrete intermediate supports are disc pillars of varying thickness, which are monolithically fixed to the span structure. The study was realized on a sunny day in the afternoon hours, when the ambient temperature was 28°C and the air
humidity was about 60%. The distance between the IR camera (FLIR T620) and bridge elements varied from 2.0 to over 35.0 m. Selected results are shown in Figure 1.

Figure 1. Results of passive thermography: a) thermal image of the intermediate support from the Ostrów Tumski side, b,c) thermograms of the plate of extreme span on the Śróđka side with abutment.

The second object is multi-spans system in the statical scheme of simply supported beams. The structure in the cross section consists of 8 prefabricated post-tensioned concrete beams of the WBS system. Theoretical spans length are 6x18.0 m. The distance between the IR camera and viaduct was about 1.0÷5.0 m. Investigation was conducted under the bridge on cloudy day, so the sky and ground-reflected radiations had no effect (the effect was very small and could be neglected) on the ambient temperature, which was 12,0 °C. The relative air humidity was 85%. The following elements of the viaduct were thermographic inspected: the abutment cap, the intermediate pier, the deck slab and the main girders. The examples of results are shown in Fig. 2.

Passive thermography can help only in assessment of the moisture degree and area of tested concrete surface. Temperature differences, that are shown on the thermograms (Fig. 1,2), are associated with different values of coefficients of emissivity degraded areas related to chemical corrosion and electrochemical corrosion of concrete reinforcing bars. In the case of delamination the situation is different. We are dealing here with the occurrence of natural IR active thermography which is associated with the appearance of daily cyclical temperature changes (sunshine, rain, wind, amount of traffic etc.) and the formation of different temperature gradients between areas that have not been and have been delaminated. Therefore, on thermograms it is possible to observe potentially delaminated areas.

Figure 2. Passive thermography results of the: a) abutment cap, b) intermediate pier, c) main girder.

4. Laboratory tests
The study focused on the analysis of the concrete slab of dimensions of 60x60x10 cm that was made of concrete of strength class C35/45. Reinforcement mesh was made of steel bars with a diameter of Ø10 and Ø12 mm in a spacing of 15.0 cm (Fig. 3a). Internal voids (Void1÷Void4) were made in the form of plastic boxes with dimensions of 7.0x4.7x1.9 cm. They were placed in the plate so that they were about 1.5 to 3.0 cm below the top (measuring) surface. Methodology of research relied on the heat flow forcing using a long, constant (rectangular) heat pulse and on recording the plate surface temperature distribution during the heating and cooling process. The PRC ANS-Centrum special
thermal excitation set, consisting of two halogen lamps with a power of 150 W, was used for the tests. Thermograph type FLIR X6540SC for creating and processing thermal images was used to carry out the measurements.

**Figure 3.** Step-heating thermography test: a) schematic position of voids and reinforcing bars in plate, b) experimental set-up (1 - IR camera, 2 - halogen lamps, 3 – tested concrete plate, 4 - computer), b) thermograms of each defects at time 10 min.

Analysis of the results shows that all simulated damages can be detected by step-heating thermography. The shallowest defect (Void 4) has already been detected in the heating phase (after about 90 sec.) and the thermal image for t=10 min shows the best shape and dimensions of defect Void 4 (approx. about 90%). Using FLIR ResearcheIR software, temperature profiles (as a function of cooling down time) at the places of defects and at the reference points were determined. Selected results are presented in Fig. 3c.

5. **Conclusions**

The use of infrared thermography for routine bridge inspections, as shown by the above mentioned studies is reasonable, but the scale and number of limitations are quite substantial. Typical disadvantages include unfavourable weather conditions, long distances between the observation point and the structure (geometric and temperature resolution), large size of bridge elements. Moreover, the actual damage is different in nature from that simulated under laboratory conditions. It is also known how difficult it is to achieve even heating of the test surface. Despite these limitations, research on the use of infrared thermography for bridge inspection should be continued, as illustrated by example in the paper [9], in order to find the best possible use of the potential of this measurement method.

6. **References**

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