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Use of Infrared Thermography to Detect Defects on Concrete Bridges

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Abstract

This paper describes the results of research conducted at the Transportation Research Centre with the focus on the use of infrared thermography regarding inspections of concrete bridges in the Czech Republic. Infrared thermography has a potential to detect subsurface delaminations before spalling develops, and could be used as a tool to enhance the visual inspection of concrete bridges. This method has several advantages, e.g. measurement is non-contact, non-destructive and is not time consuming. The main aim of the presented research is to evaluate the possibility of infrared thermography to detect defects on bridges in practice.

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1. Introduction

Infrared thermography is increasingly used in many industrial applications, such as monitoring of electric lines, inspections of houses and detection of discontinuities in composite materials. Its use in the inspection of transport infrastructure is not common in Central Europe.

In the Czech Republic there are around 17,000 road bridges; thousands more of railway bridges and footbridges [1, 2]. Up to three thousand road bridges are in poor condition. The majority of road bridges are made with reinforced concrete and pre-stressed concrete. These constructions, mostly dating to the 1970s and 1980s, may be subjected to some typical pathologies induced by ageing, such as corrosion of reinforcing steel accompanied by the delamination of the concrete.

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In the Czech Republic, the evaluation of bridge conditions is made according to the ČSN 73 6221: Inspection of Road Bridges [3]. This standard distinguishes four types of inspection, e.g. routine inspection should be carried out once or twice a year. The main inspection is conducted every two, four or six years depending on the bridge condition. It is not always easy to check all parts of the bridge carefully. Problems can occur at high structures or on bridges with heavy traffic. In such situation it is difficult to detect the deterioration early at the beginning of the damage process when cost-effective rehabilitation strategies could be employed to extend the service life of a bridge and to ensure safety. Infrared thermography (IR) offers a potential solution to these inspection challenges [4-6].

Historically, IR thermography has been used for the detection of delaminations and debonding in highway bridge decks in the United States. An ASTM standard test method for applying the technology for bridge decks was first approved in 1988 [7]. This standard test method describes environmental parameters and certain procedures for conducting evaluations of concrete and asphalt covered bridge decks based on limited field testing. The standard provides guidance on weather conditions necessary to conduct infrared imaging of bridge decks, such as the number of hours of direct sunlight needed, maximum wind speed and a minimum range of ambient temperature change for conducting inspections during winter months [8]. There is no standard for the use of thermographic methods for bridge inspections in Europe.

2. Background

One of the types of defects which can be observed during an inspection of a concrete bridge is a delamination of the concrete covering. The delamination is often caused by the steel reinforcement corrosion under the concrete construction surface. Reinforced concrete is nowadays one of the most commonly used materials. The steel reinforcement provides reinforced concrete with the necessary tensile strength, which normal concrete lacks. The reinforcement prevents failures of concrete structures, which are exposed to tensile and flexural stresses due to dead loads, traffic, wind or thermal cycling.

Correctly designed and built bridge must endure decades without larger repairs. Bridge structures are often exposed to adverse weather conditions. Aggressive substances, such as chlorides, may penetrate concrete and change its chemical properties. Reinforcement corrosion is often preceded by the concrete cover carbonation. Over time CO_2 penetrates the concrete together with air and reacts with $Ca(OH)_2$ – portlandite, contained in concrete. $Ca(OH)_2$ dissolves into $CaCO_3$ and water. As CO_2 propagates into concrete, $Ca(OH)_2$ diminishes reducing the pH of the cover layer. Once concrete pH drops below the value of 9, a small layer of iron oxides disintegrates between the reinforcement and concrete. At this moment water and oxygen have access to the reinforcement and the reinforcement corrosion begins.

The main protection against steel reinforcement corrosion in bridges is quality and sufficient thickness of concrete cover above the reinforcement. The lower depth of reinforcement below the concrete surface, the sooner comes the threat of corrosion in case the concrete surface is exposed to adverse weather conditions. Corrosion products have substantially bigger volume than the original metal. Their occurrence leads to increased pressure to the concrete cover layer. Higher occurrence of corrosion products pushes the pressure to creation of cracks and delamination of the concrete cover. Subsequently, parts of the concrete can be completely separated. In case of another road under the bridge, there is a threat of damage to passing vehicles or even injuries of people hit by a separated concrete pieces. IR thermography can help to detect these defects sufficiently in time under good conditions.

Bridge surface temperature can be relatively accurately measured thanks to the infrared camera. However, sufficient thermal sensitivity is much more important to detect potential defects. Modern infrared camera may reach thermal sensitivity of up to $<0.02°C$. Thanks to this sensitivity, it is possible to observe even slight thermal differences on the bridge surface. Bridge temperature changes in relation to ambient temperature. The effect of sun radiation and increasing air temperature first warms up the object surface, from where heat moves deeper into the structure. In contrast, in case ambient temperature decreases (at night), the structure cools down and heat spreads in the other way. The speed heat spreads in the structure depends on heat conductivity, which is directly proportionate to thermal difference (ΔT) between the heat transfer spots.

Regarding the changes of temperature of a bridge with defects, it is possible to observe that the structure surface heats unevenly. In case there is a defect under the structure surface, the air gap works here as “insulation”, which limits heat flow. In case ambient temperature rises, this defect causes the surface above to heat more than a structure