Numerical investigation of infrared thermography application in tunneling

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ABSTRACT
Deterioration in concrete lining of the tunnels by time is a frequent problem in cities with old underground construction. Infrared thermography is a non-destructive and contact-free method to detect the deflections in the damaged concrete lining. In this method by taking thermal images of the defected concrete lining defected and then analyzing of it, the non-visual subsurface abnormalities can be detected by temperature difference around the defected area. In this study, infrared thermography was employed in a shield tunnel with box-type segments and thermal field data were measured. The data include tunnel air temperature, the surface temperature of sound and damaged part of concrete parts. A numerical model is employed to simulate heat transfer mechanics in this site using the measurement data. In numerical analysis, convection, conduction, and radiation heat transfer mechanics were taken into consideration. After verifying the numerical model results with measurement data, the model is used to investigate the influence of depth and orientation of void on detection accuracy.

Keywords: Tunnel lining defection, void orientation, heat transfer

1. INTRODUCTION

Non-destructive contact-free methods are widely used for the investigation of anomalies in concrete structure [1]. Among these methods, infrared thermography (IRT) is recently employed in underground structures such as old tunnels to detect the location of hidden voids and cracks [2]. The IRT can be used in either of active and passive methods. In the active method, an external source of heat is used to create a temperature difference between concrete surface and ambient air; However, in the passive one natural temperature difference in the tunnel is used. The active IRT in tunneling takes a lot of time and is costly, therefore it is preferred to apply passive IRT in underground construction [3]. As temperature changes in the tunnel are small because of no direct solar radiation, it is important to apply the method when the adequate temperature difference between tunnel air and concrete surface is available. There have been attempts to measure the heat transfer rate in the concrete wall and then simulate the same phenomenon by numerical means [4,5]; however, there are very few investigation cases about the application of IRT in tunneling. This paper discusses some aspect of heat transfer mechanism in defected tunnel lining numerically.

In this study, infrared thermography was employed in a shield tunnel with box-type segments and thermal field data were measured along the tunnel. The thermal data include the tunnel air temperatures and the surface temperature of the sound and defected concrete parts. A numerical model is employed to simulate heat transfer mechanics in this site using the measurement data. After verifying the numerical model results with measurement data, it is used to investigate the influence of depth and orientation of the defect on detection accuracy.

2. DATA OF THERMAL MEASUREMENTS

The studied case is a box type tunnel excavated by cut and cover method. It is 2 km length railroad tunnel in operation. Fig. 1 shows the cross-section of this tunnel. Hammering test and IRT method were performed in this tunnel to detect non-visible voids. The hammering tests were conducted to compare its results with the IRT method.

Figure 1. RC tunnel cross section.

The field thermal measurements include the tunnel air temperatures and the surface temperature of the sound and defected concrete parts. (Fig. 2) shows the hourly tunnel air temperature changes during a day on this site.

Figure 2. Field data of tunnel air temperature by time.
detect the location of the void. (Fig. 3) shows a thermal image from the site under this study. The surface temperature ranges on the concrete lining are between 22.1 °C and 23.1 °C. The temperature around the voids in this figures depicts lower temperature in comparison with other parts.

3. NUMERICAL INVESTIGATION

3.1. Numerical model

A numerical model is employed to simulate heat transfer mechanics in this site using the measurement data. After verifying the numerical model results with measurement data, the model is used to investigate the surface temperature difference between the sound and defected concrete surfaces, and influence of defect depth and orientation on detection accuracy. The numerical model includes a concrete segment on the ceiling of the RC tunnel with the width, length and thickness of 100 cm, 80 cm, and 30 cm respectively. Because of symmetry, only half of segment length (i.e. 40 cm) is used in the numerical model. Fig. 4 shows the numerical model of the defected tunnel lining. The heat transfer between the defected concrete lining and tunnel air are due to conduction, convection, and radiation mechanisms. The soil is in contact with the external surface of the concrete surface with a constant temperature of 16 °C and absorbs heat via the steady convection mechanism. The tunnel air and the internal surface of the segment transfer heat with the tunnel air by transient convection mechanism. The temperature of tunnel air varies hourly according to the measurement data shown in Fig. 2. The void located inside the surface at a depth of a few centimeters, exchanges heat through its surfaces by radiation. The surface temperature of the concrete segment is unknown. The model does not exchange heat by the side boundaries.

![Figure 3. Thermal image of defected part of the RC tunnel](image)

Figure 3. Thermal image of defected part of the RC tunnel

3.2. Effect of void depth and orientation

In this part, by using the developed model, the influence of the depth and orientation of the void is taken are investigated. The numerical model is verified by fitting the numerical results and field measurement results. The depth of the void is an important factor for locating the defect. As the void is getting deeper, the detection rate of the void is decreasing. The void shown in Fig. 4 is horizontal. The results indicate that the void blocks the heat flow path in and out of concrete around the defected area. Normal void depths in the damaged concrete lining of the tunnel is reported to be between 19 and 30 cm. In the case of shield tunnel, the voids in the tunnel lining happen due to corrosion of steel bars in the depth of from 19mm to 30mm. The void depth is changing in this study between 10 mm to 50 mm and orientation of the defection varies between 0 degrees to 45 degrees. The influence of the depth and orientation angle of the void with respect to the concrete surface is investigated in this study.

### Input parameters

Input parameters of the numerical model are listed in Table 1. Among the heat thermal parameters, specific heat, thermal conductivity and emissivity are selected by referring to the previous literature, but heat transfer coefficient is chosen by fitting the results of numerical analysis and field measurements.

<table>
<thead>
<tr>
<th>Input parameters (concrete)</th>
<th>Input values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific heat, c</td>
<td>1150</td>
<td>J/kg.K</td>
</tr>
<tr>
<td>Thermal conductivity, k</td>
<td>0.5</td>
<td>W/m.K</td>
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<tr>
<td>Heat transfer coefficient, h</td>
<td>3</td>
<td>W/m².C</td>
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<tr>
<td>Emissivity, e</td>
<td>0.92</td>
<td>-</td>
</tr>
</tbody>
</table>

### References