Transient Thermography for Detecting Corrosion Damage in Concrete

by Dr. Glenn A. Washer, University of Missouri

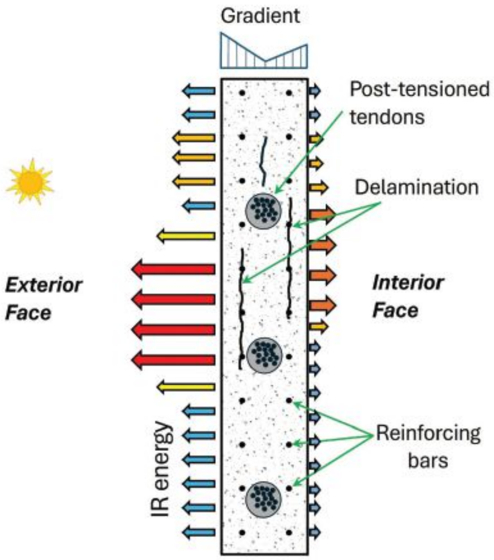

Figure 1. Illustration of conventional infrared thermography showing infrared radiation from the interior and exterior surfaces of a post-tensioned box girder. All Figures: ThermalStare LLC.

Effective condition assessment of concrete structures is critical to maintaining structures and ensuring safety. Corrosion damage in concrete is a problem, often manifesting in spalling that decreases the strength of the concrete component and exposes the embedded reinforcing steel to the environment. Methods to detect areas of subsurface delamination that precede spalling can provide early indications of corrosion damage, identify areas requiring repair, and assist engineers in ensuring the safety and serviceability of conventionally reinforced, pretensioned, and post-tensioned concrete structures. Infrared ultra–time domain (IR-UTD) imaging is a new, nondestructive tool based on transient infrared thermography (IRT) to detect subsurface corrosion damage in concrete. It captures thermal data over time to provide more reliable detection of corrosion damage in its early stages and identifies emerging corrosion issues in large concrete structures.

Corrosion Damage

Corrosion damage initiates below the surface of the concrete where embedded reinforcing bars corrode due to exposure to moisture and corrosive agents. Hidden from view in its earliest stages, the corrosion causes the steel bars to expand, introducing tensile stress in the concrete. Cracking relieves the tensile stresses and can produce areas of subsurface delamination. As the corrosion process progresses, the subsurface damage emerges toward the surface and can produce spalling of the concrete that weakens the concrete structure and exposes internal reinforcement to additional corrosive elements.

To prevent spalling, it is critical to identify areas of the subsurface where moisture and corrosion agents are penetrating the concrete, exposing reinforcement and embedded post-tensioned tendons to a corrosive environment. Detection of evolving corrosion damage in its early stages can identify areas in need of repair or the need for further exploration such as intrusive inspections to assess the integrity of the protective layers of embedded post-tensioning tendons or pretensioned strands.

Conventional Infrared Thermography

Conventional IRT has been used to detect subsurface damage based on the thermal anomalies appearing in images of the surface of the concrete. The technology depends on significant daily temperature variations to produce a thermal gradient in the concrete. **Figure 1** illustrates the increased thermal energy emitted from areas of subsurface damage that heat more rapidly than intact areas of concrete due to the reduced thermal mass. The thermal contrast, which is the difference in temperature between an intact area and a defect area measured at the surface of the component, appears as different colors in an IRT image. **Figure 2** presents quantitative data from thermal images to illustrate the detection process. The graph shows the ambient temperature variations over a 24-hour interval in which temperatures are cool at night, increase during the morning hours, and decrease again during the afternoon. The thermal contrast from a simulated subsurface defect is referenced to the secondary vertical axis on the right. This thermal contrast varies over the course of the day, and at times, there is no thermal contrast ΔT produced by the subsurface defect, resulting in no color difference in an IRT image.

Therefore, the reliability of IRT for detecting subsurface damage varies depending on the surrounding environmental conditions and varies throughout the course of a day. IRT results can be difficult to confirm through repeat testing because exact ambient conditions are rarely reproduced. The magnitude of the thermal contrast depends on ambient temperature changes, exposure to solar heating, and the depth from the surface to the damage. The magnitude of the thermal contrast is reduced significantly as the depth to the damage increases, when ambient temperature changes are small, or when solar loading is not present. Conventional IRT is typically most effective when the damage is 2 in. or less from the concrete surface and ambient temperature changes are large (greater than 15°F to 20°F) or direct solar loading is present. Additionally, for thermal contrasts from damage to be detectable, the damage-related thermal anomalies must exceed thermal anomalies produced by other surface features such as paints, stains, or areas where surface roughness varies.

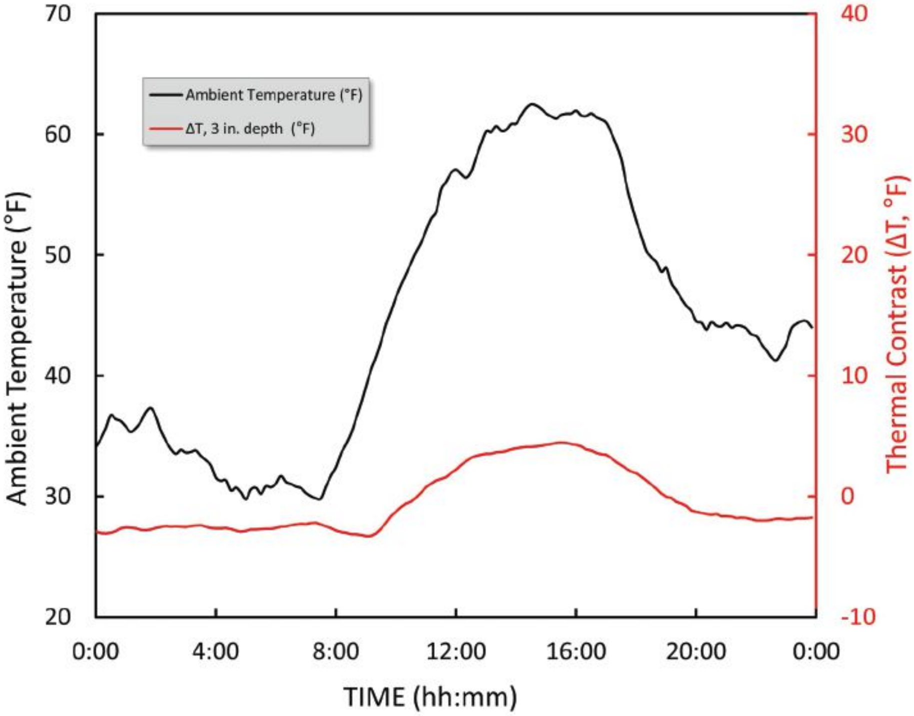

Figure 2. Quantitative data from thermal images show the ambient temperature variations over a 24-hour interval on the left axis and the thermal contrast from a simulated subsurface defect at a depth of 3 in. on the right axis. The thermal contrast is the difference in temperature between an intact area and a defect area measured at the surface of the component.

Infrared Ultra–Time Domain Technology

IR-UTD imaging overcomes the environmental limitations of conventional IRT by using advanced signal processing algorithms that use time-lapsed data to analyze heat flow through the concrete. The heat flow is affected when there is subsurface damage in the concrete. **Figure 3** shows how thermal images are captured periodically throughout the heating and cooling of the concrete structure, and these data are analyzed to produce images showing the subsurface features in the concrete.

IR-UTD technology differs significantly from conventional IRT because the new technology captures thermal images throughout the heating and cooling of the day and night. The thermal data are postprocessed to detect the thermal wave (heat flow) propagating through the concrete rather than simply identifying surface temperature anomalies at any single point in time. Compared with conventional IRT imaging, heat-flow analysis can better distinguish between real damage and surface features that produce thermal anomalies because those features behave differently than damage when analyzed over time. Also, IR-UTD technology can identify the inertial effects of subsurface features, so it facilitates detection of damage and other features at much greater penetration depths than can be achieved with convention IRT imaging. For example, IR-UTD technology can be used to image internal diaphragms or supporting members through a concrete deck (Fig. 3).

IR-UTD technology creates easy-to-interpret images showing subsurface damage and structural features of buildings, bridges, dams, tunnels, and other structures. Quantitative, reliable, and reproducible images can be obtained without the use of traffic control or lane closures for highway bridges, or without access to the large surface areas of other concrete structures such as buildings, tunnels, or dams.

Thermal cameras embedded in the IR-UTD technology system use wide-angle lenses and scanning technology to collect data on bridge decks over an area of 15,000 ft^2 from a single setup location with a spatial resolution of less than 1 $in.^2$. For highway bridge decks, cameras are typically mounted 35 to 40 ft above the deck. For large structures such as cooling towers, dams, or buildings, telephoto lenses are used to produce images of similar resolution from large distances. The IR-UTD images are accompanied by images that document the corresponding visual condition of the surface.

Whereas hammer-sounding and nondestructive technologies such as impact echo or ground-penetrating radar require access to the surface of

Figure 3. Transient infrared thermography concept presenting time-lapse imaging and the resulting infrared ultra–time domain images showing corrosion damage in a bridge deck.

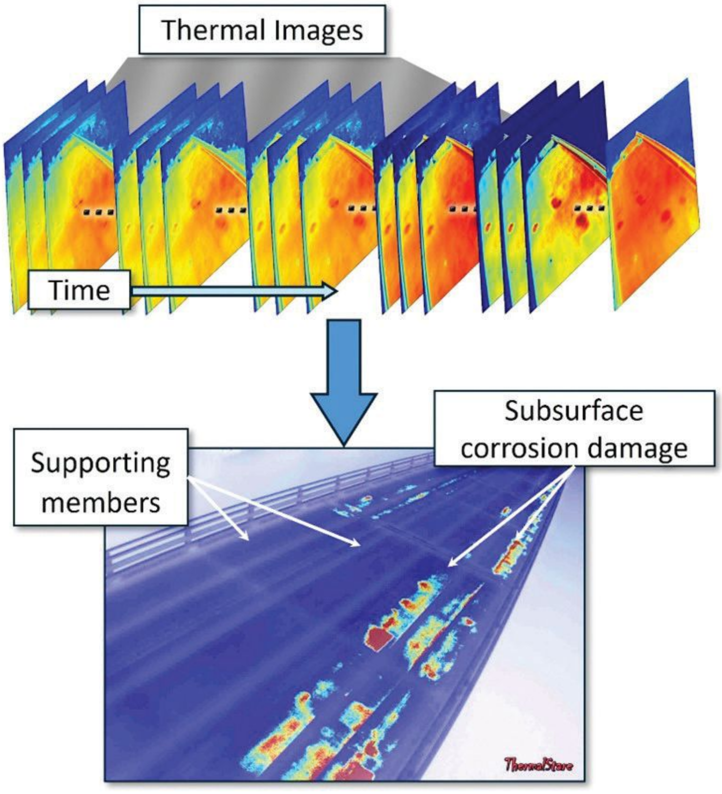

Figure 4. Using a camera installed at ground level, infrared ultra–time domain (IR-UTD) images are taken of a concrete cooling tower (left). Thermal and visual images depict the IR-UTD vertical scan-ning area from the base to the top of the 500-ft-tall tower (center). At an elevation of 470 ft, areas of defective concrete are shown in infrared data superimposed over a graphic image of the tower (right).

a structure, IR-UTD can be used to evaluate large structures without such access. For example, **Fig. 4** shows the application of IR-UTD technology to a 500-ft-tall cooling tower. The IR-UTD technology was mounted on a tripod at ground level and scanned the entire height of the tower (Fig. 4, left). Figure 4 (center) shows visual images captured during vertical scanning from the base to the top of the 500-ft tower. Both thermal and visual images are captured during the vertical scan. Figure 4 (right) shows a single thermal image superimposed on the visual image of the top of the tower and then a zoomed-in view with the subsurface damaged areas circled. The defect areas can be quantified in the IR-UTD image, such that the total area of damage can be determined by summing the individual defect areas.

IR-UTD technology rapidly collects images during heating and cooling of the concrete surface and analyzes the heat flow through the concrete to detect damage at greater depths than previously possible with conventional IRT. The ability of IR-UTD to detect subsurface damage when asphalt, concrete, or polymer coatings are present is unique among nondestructive evaluation technologies currently available for condition assessment.

State departments of transportation can use this new technology for quantitative assessment of repair needs because the technology produces accurate and repeatable measurements of corrosion damage. IR-UTD technology is often employed during rehabilitation planning to identify critical areas for coring to assess structural capacity, material properties, and the extent of deterioration in a structure. For post-tensioned structures, IR-UTD technology can quantify damage and indicate areas where subsurface corrosion damage is evolving, which helps investigators locate critical areas for intrusive inspection to assess the corrosion protection system of internal tendons. Current and future applications for IR-UTD technology include inspection of concrete bridge decks and deck soffits, buildings, tunnels, dams, and other large civil structures where detection and characterization of corrosion damage is critical for ensuring safety and serviceability.

Dr. Glenn A. Washer is a professor of civil and environmental engineering at the University of Missouri. He previously served as the director of the Federal Highway Administration's Nondestructive Evaluation Program at the Turner-Fairbank Research Center.