Inspection of Heritage Structure using Infrared Thermography

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Abstract

The heritage structures in India are well-known for brilliant architecture, stone carving, sculptures, cave paintings and temple construction etc. These structures built in the remote past by traditional methods have suffered the consequences of extreme loading events, such as earthquakes, wind, impact etc. over long time periods, often leaving them disjointed and degraded. Materials used in these structures are subjected to degradation due to different environmental changes (viz. climate changes, air pollution, ground water pollution etc.). Therefore, condition monitoring of these structures are absolutely necessary before carrying out any conservation and restoration work. Non-destructive testing and evaluation can be adopted for the assessment of present condition of these structures. Infrared Thermography Testing (IRT) has become a matured and widely accepted NDT method for inspection of these structures where the temperature is measured in real time in a non-contact manner. IRT is used in the present study by CSIR-CBRI team for the condition assessment of heritage structures Solani Aqueduct and Government Irrigation Workshop, Roorkee. The moisture damages, defects in the medium, cracks etc. are imaged using IRT images. The obtained results show the current state of the structures and confirm the application of IRT as a NDE technique for heritage structures.

Keywords: Infrared Thermography, heritage structures, Non-destructive testing, condition monitoring

1. Introduction

Infrared thermography (IRT) is a non-contact and Non-Destructive Testing (NDE) technology that can be applied to determine the surface temperature of an object. It is commonly used as a diagnosti tool to study the thermal behavior of building elements to identify anomalies and degraded areas. Infrared Thermography Testing (IRT) has now become a matured and widely accepted NDE method for inspection of these structures where the temperature is measured in real time in a non-contact manner. Thermal camera captures information in the infrared spectrum of light invisible to people, thus it can provide valuable extra information. Innovative use of thermal imaging technology can therefore play an important role in many civil engineering applications [1]. The effect of moisture in buildings is normally related with damage, which may occur due to the presence of moisture itself or due to its evaporation. The drying process plays an important role in the available moisture, both inside the material or at its surface, so its evaluation is of great importance. Infrared thermography is also used by researchers for the investigation of concrete structures which includes examining surface and subsurface defects [2], delamination of surface layers [3], damage evaluation of steel-plate concrete composite walls [4]. The possibility of detecting very small defects in concrete was presented, representing disbands, voids and in-homogeneities, using the thermal imaging technique and results were compared with ultrasonic pulse velocity (USPV) technique [5]. Researchers have performed active thermography on concrete [6]. This technique is more applied in detecting damages in materials and structures that are not exposed to direct sunlight. Evaluation of steel fibre distribution in cement-based mortars using active microwave thermography [7] have been performed.

Nowadays, IRT is being also explored for examining the cultural Heritage. The use of Pulsed Thermography (a type of active thermography) for the investigation of art and cultural heritage objects has been presented [8]. A case study has been done on a historical building at Calabria, South Italy by using a combined methodology of terrestrial laser scanning and the
IRT, in order to find out the capabilities both to detect the anomalies and extract the health information of the masonry building [9]. Four case studies on Historic buildings from USA and Italy have been studied to illustrate how IRT can be used for building's materials, its condition, characteristics and state of decay can be gathered that may not be evident from visual examination [10]. IRT is also applied for the investigation of art and historic artefacts [11]. It was concluded that infrared thermography either through the passive configuration or through the active one can act as a useful tool for the evaluation of heritage or mosaic structures [12]. Thermographic images are even used to analyse the response of a masonry structure under seismic actions [13]. IRT has been used in the current study for the investigation of heritage structures situated at Roorkee, Uttarakhand.

2. Methodology

IRT techniques can be divided into two categories, classified as passive and active thermography. The passive methods monitor the infrared (IR) emission associated with the temperature evolution due to the heating and cooling phenomena naturally occurring in the investigated system and the active thermography includes the heating up of the sample by an external agent within a limit to gain radiation from it. The thermography is based on the emission from a objects based on three essential radiation laws:

1. Kirchhoff’s law of thermal radiation, establishes the relation between emission and absorption of energy, indicating that a body which absorbs much also emits much and, according to this principle, the emission coefficient, $\varepsilon$, is introduced in equation as the ratio of emissivity, $E$, of a real body to the emissivity, $E_s$, of the black body under the same temperature $\varepsilon = E / E_s$. The emission coefficient, $\varepsilon$, is non-dimensional and takes values between 0 and 1 and depends on the wavelength, on the temperature and the surface texture of the body.

2. Planck’s law of radiation describes the specific spectral radiation $I'$ emanating from the idealized black body.

$$I'(\lambda, T) = \frac{2\pi c^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$  \hspace{1cm} (1)

Where: $\lambda$ is the wavelength, $T$–the absolute temperature, $h$–the Planck constant and $c$–the speed of light.

3. Stefan–Boltzmann law, applied to the emission of a surface over all wavelengths, integrated the Planck law and discovered that the radiant power, $I$, [W/m$^2$], grows with the fourth power of the temperature,

$$H = \sigma T^4$$  \hspace{1cm} (2)

where $\sigma = 5.67 \times 10^8$ W/m$^2$ K$^4$.

Passive thermography technique is used for the imaging of the selected heritage structures. The structures are exposed to heat from sunlight during peak hot hours (morning and noon). The images are captured in the afternoon.

3. Case Studies

Two heritage structures 1) Solani Aqueduct (Figure 1a) and 2) Government Irrigation workshop (Figure 1b) in Roorkee city has been is inspected by CSIR-Central Building Research Institute, team for health assessment of the structures. India's first aqueduct was constructed over the Solani River in Roorkee during on 1846. As documented, Government
Irrigation Workshop, Roorkee was constructed in 1843 during construction of Upper Ganga Canal. It also served as army workshop during war in 1903.

![Solani Aqueduct](image1)

![Irrigation workshop at Roorkee](image2)

**Figure 1** (a) Solani Aqueduct (b) Irrigation workshop at Roorkee

### 3.1 Thermography of the Solani aqueduct at Roorkee

Thermal imaging of Solani aqueduct has been carried out from a distance of 400m. Fluke Tix660 has been used for the study. The visual image and thermal image of the aqueduct is shown in Figure 2a and Figure 2b. The defected areas of the aqueduct bridge are shown in the thermal image (Figure 2b). The dark stains in the visual image indicates the degradation of the structure. The main cause of the degradation of the aqueduct bridge is, it is exposed to adverse environmental conditions viz. thermal and mechanical stresses and variation of humidity.

![Solani aqueduct bridge side view](image3)

![Thermogram of solani aqueduct bridge](image4)

**Figure 2** (a) Solani aqueduct bridge side view (b) Thermogram of solani aqueduct bridge

Some other locations of the aqueduct are also investigated. Entrance of the north side base is also imaged with the thermal camera (Figure 3). Defected locations are marked as ellipses in the thermal image. Structural deterioration, vegetation growth is observed.
The passage in the aqueduct is also imaged where both side of the road is degraded severely as shown in Figure 4. Moisture seepage is clearly observed in the track.

![Figure 4. Thermogram of Solani aqueduct passage](image)

3.2. Thermography of the Irrigation workshop

Most of the locations of the structure was in intact form. However, it is severely damaged at some locations. The structure is 174 years old and some locations are heavily damaged due to moisture ingress and weeds grown over and top of the structure. The visual and thermal image of a particular location of the workshop is shown in Figure 5. Moisture ingress, cracks and degraded portions in the structure can easy be localized in the thermal image. The continuous flow of water from the top and also the accumulation of the water causes the structure to gain high moisture. It eventually resulted degradation of structures at several locations.
Figure 5 (a) Visual image (b) Thermal image of workshop

Thermal images at other location of the workshop buildings are shown in Figure 6 and 7. The roots of the plants growing at roof of the structure can easily identified from the thermal images. At several locations plants penetrates into the walls of the workshop and resulted cracks. Heavily moisture presence can also be identified from the images.

Figure 6 (a) Visual image (b) Thermal image at carpentry shop of workshop

Figure 7 (a) Visual image (b) thermal image carpentry shop of workshop
The damage due to moisture ingress can very easily be identified in the thermal images (Figure 8) of many locations.

![Figure 8](image1.png)  ![Figure 8](image2.png)

Figure 8 (a) Normal image (b) Thermal image

At many locations of the underground building of the workshop, have cracks and damages. The thermal image of one of such location is shown in thermal image 9b.

![Figure 9](image3.png)  ![Figure 9](image4.png)

Figure 9 (a) Normal image (b) Thermal image of underground building

Individual brick layers and damages in the masonry is clearly mapped in the thermal image shown in Figure 10.
Re-construction under masonry arch structure and a crack in the construction joint is also clearly observed in thermal image (Figure 11b).

Figure 11 (a) Normal image (b) Thermal image of filled up masonry structure

The presence of moisture ingress is observed throughout the structures. The major reason for degradation of masonry is moisture ingress into the structure.

**Conclusion**

The main objective of this paper is to present the effectiveness of infrared thermography as a NDT&E technique for the investigation of historic structures. It contains an overview of infrared thermography and its applications relating to the investigation of historic structures. From the present diagnostic studies on the historic structures at Roorkee, it can be concluded that IRT provides significant information about the present condition of the structure. It is a non-contact technique, therefore can be operated remotely. Based on the thermographic inspection the damages in the heritage structures may be identified. Therefore, thermography should to be considered as an appreciated tool for the conservation and restoration of heritage structures.
References:


