

## THERMAL IMAGING OF CONCRETE DAM SURFACES TO SUPPORT THE CONTROL OF THE EVOLUTION OF PATHOLOGIES

Maria João Henriques\* and Pedro Ramos†

\* Laboratório Nacional de Engenharia Civil (LNEC)  
Av. do Brasil, 101, 1700-066 Lisboa, Portugal  
e-mail: mjoao@lnec.pt, webpage: <http://www.lnec.pt>

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**Abstract.** *The pathologies of structures that cause changes of surface temperatures can be detected by the analysis of the temperature of walls and other surfaces. Temperature measurements can be easily performed with the use of thermal imaging cameras which work like an ordinary digital camera and give, instantly, a colour image where the colours are related with the temperature of the surface. This paper presents a study of the use of this methodology in the monitoring of concrete dams, specifically on the detection of resurgences of water on the downstream face, which are usually related with the transfer of water.*

### 1 INTRODUCTION

In the inspection of Civil Engineering structures, thermal cameras are mainly used to identify insulation failures and seepage areas (Figure 1). The analysis of images of the surface temperature of walls, ceilings, etc., can be used to identify variations of the temperature of the surfaces and help to locate, precisely and instantly, cooler areas which are mostly related with abnormalities of construction or with aging of materials.

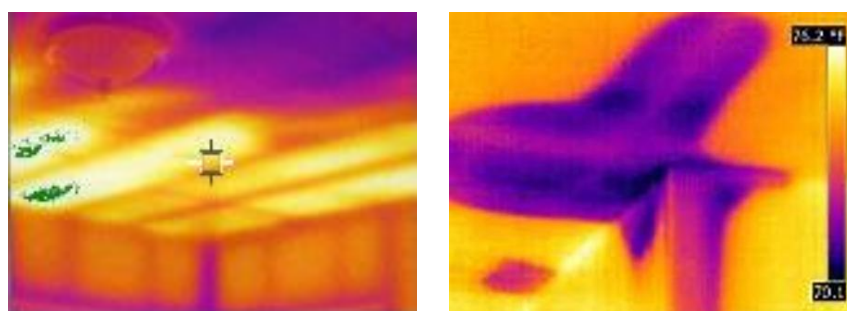


Figure 1: Thermal images from ceilings in two buildings. The first ceiling reveals insulation deficiencies, the second water seepage.

In concrete dams, the analysis of thermal images of the downstream face may alert to the existence of resurgences of water, including their location and extension. If this type of

† Município EM S.A. - Empresa de Cartografia e Sistemas de Informação

monitoring is carried out systematically, with some care in how images are obtained, it can be used to determine, with great accuracy, the evolution of the areas affected by seepage. And if the survey is conducted on a regular basis and starts in an early stage, after the construction of the dam, the detection can be done early, before the appearance of the deposits of carbonates on the surface of the dam.

The evaluation of the use of this technique was performed in three Portuguese dams – Alto Ceira, Cabril and Alto Ceira II – being that a resume of the results<sup>1</sup> are presented in this paper.

## 2 MEASUREMENT OF SURFACE TEMPERATURE IN THREE DAMS

The thermal survey of the downstream faces of the three dams was made on the 4<sup>th</sup> of June of 2013. That day was mostly sunny and the air temperature reached 26°C in Alto Ceira dams and 30° in Cabril dam (maximum values). The images were taken by a thermal camera FLIR T335, from Municipia, a small and light-weight (880 g) camera with two sensors: a 320×240 pixels infrared sensor to acquire thermal images, sensible to far infrared radiation (range 7.5-1.3 μm), and a 2048×1536 pixels sensor to acquire normal images or videos (visible radiation). In Table 1 are presented the metric characteristics of the images.



Figure 2: Thermal camera FLIR T335

Distance	Pixel dimension		Area covered by the image	
	thermal	visible	width	height
20 m	2.8 cm	0.4 cm	9 m	6.7 m
50 m	8.4 cm	1.3 cm	26.9 m	20.2 m
100 m	14.0 cm	2.2 cm	44.8 m	33.6 m

Table 1: FLIT T335 image metrics as related with the distance from the camera to the object.

The measurement of the temperature at distance, with no contact with the object, is possible because thermal cameras can measure the intensity of the infrared radiation and also because there is a direct relation between temperature and the intensity of the radiation emitted. The radiation sensed by the camera has three main sources: i) the emitted by the surface of the object (and is directly related with its temperature); ii) the reflected by the surface of the object and with origin in other objects nearby; and iii) emitted by the air that is between the object and the camera. So, to have accurate values is necessary to have information about<sup>2</sup>: i) emissivity of the objet; ii) relative humidity of the atmosphere; iii) temperature of the atmosphere; iv) distance camera – object; and v) temperature of the surrounding surfaces. If all/some of this data can't be provided is still be possible to use

the information given by the camera to detect variations of temperature, and use this data as qualitative data and, by no means, as quantitative information. During the thermal surveys of the three dams it was provided data to the five variables described. This way, the images present “real” temperature of the three downstream faces.

Inside the camera, the radiation measured is transformed in an image, being that the user can choose the palette, i.e., the way that the image is coloured. In the thermal survey of the dams here presented it was used the “rainbow” palette, where the cold areas are blue, the hot areas are red and the hottest ones white. In the images of Figure 1 it was chosen the “iron” palette.

### 3.1 Alto Ceira Dam

The Alto Ceira dam is an arch dam that presented, as a result of alkali-aggregate reactions, an abnormal behaviour which led to the need of its demolition. This one started two weeks after the thermal survey. The dam surface was heavily covered with cracks and seepage was presented in several areas.

The camera was mounted on a tripod which was placed on the left bank, about 100 m away the dam. The thermal survey of the downstream face took seven minutes and it were recorded 26 images. Later, on a computer, these images were stitched, creating a panoramic image (Figure 3) a procedure that took less than one hour. On the image the blue areas are the coldest ones. On the dam is possible to see some hot areas: two vertical pipes, a horizontal walkway with a guard rail, the crest.

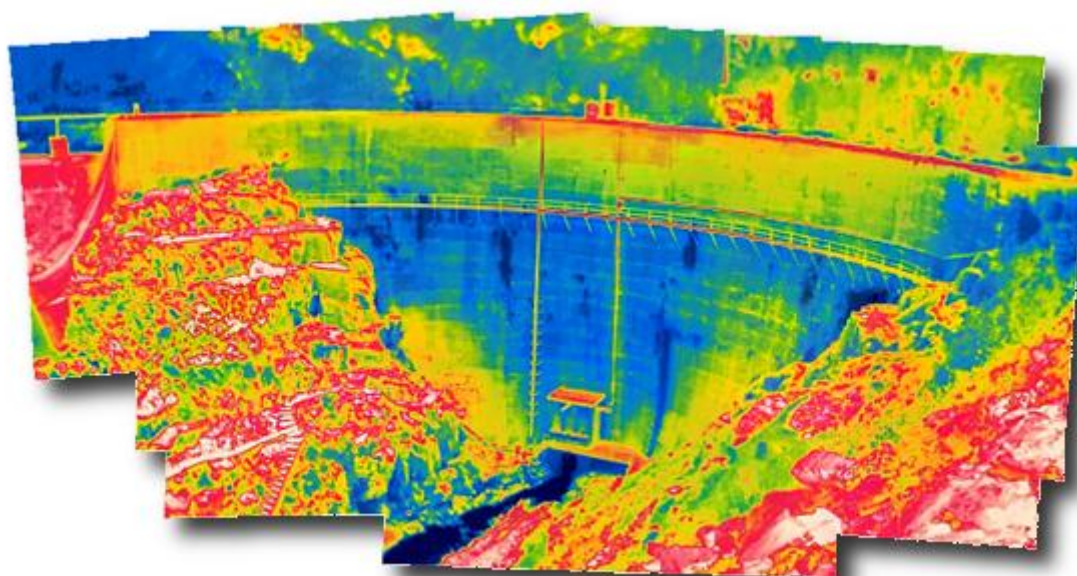


Figura 3: Thermal panoramic image of Alto Ceira dam.

During its “life”, the downstream face of Alto Ceira dam was carefully inspected three times. The last one, in 2001, was completed in about one month (time that includes the mounting of a crane-held basket). The information collected (areas covered by carbonates, wet areas, location of cracks, etc.) was integrated into an image and it was also related with data from previous inspections, conducted in 1986 and 1994. The lines of this image, presented in <sup>3</sup>, which delimit areas like wet areas or lines that signalize features like cracks, were superimposed on the panoramic thermal image, corrected of geometric deformations related to the acquisition of the images. Figure 4 shows the thermal panoramic image with occurrences overlapping it.

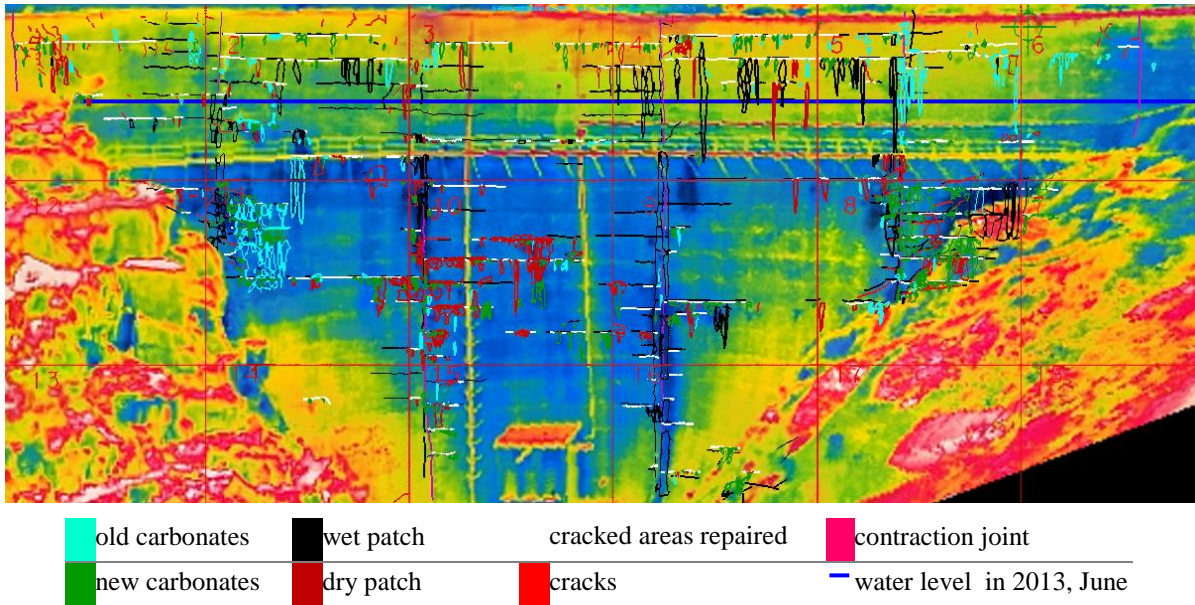


Figure 4: Occurrences, surveyed in 2001, overlapping the thermal panoramic image of Alto Ceira dam

On the thermal imaging one can noticed that many of the areas that in 2001 were “wet patches” are, on the thermal images, cooler zones. At the top of the wall the thermal survey didn’t detected cold areas. This is normal because the water level in the reservoir was 4 m below the maximum level; in 2001 this level was near the maximum. And it can also be noticed that there are cold areas (thermal survey of 2013) that don’t have any match with the wet areas of 2001.



Figure 5: Panoramic image of Alto Ceira dam

In the visible image of the dam (Figure 5), one can noticed several white patches on the downstream face. These are deposits of carbonate. Because they are white is impossible to know if there is still a transfer of water. On the other hand, is possible to detect if the concrete is wet because its colour becomes darker. It is important to noticed that some of the long darker strips, for instance along the central cantilever, are dirty areas, some due to fungus. Using thermal images is easy to notice if in the white areas there is still a transfer of water. Overlapping thermal data (as in Figures 7 and 8) on a

normal, “visible”, photo (as in Figure 6) makes it possible to notice the areas where the water is not flowing because the cracks are filled (see Figure 9).



Figure 6: Photo of the downstream face with colour enhancement.

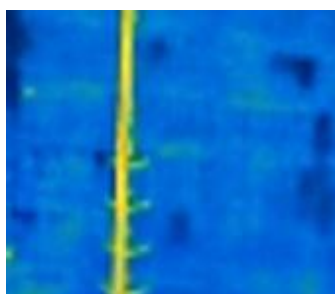


Figure 7: Thermal image of the same area.

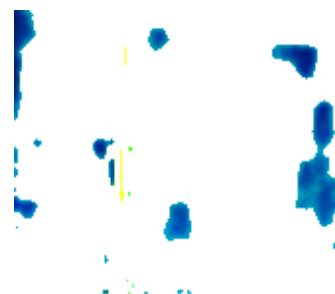


Figure 8: Cooler areas (dark blue areas of Figure 7).



Figure 9: Overlapping of the image of Figure 8 on the image of Figure 6.

### 3.2 Cabril Dam

Cabril dam is also an arch dam that faces some structural problems that originated a significant horizontal cracking in the upper areas of the downstream face. On this face there were placed two catwalks to allow the access to the most damage area.

The thermal survey was conducted in four minutes (17 images) from the left bank, near the crest height, about 340 m away the centre of the dam. At that time of the day, half dam was shaded by the right bank. The thermal panoramic image and the normal image are presented in Figure 10. On the visible image one can see long vertical strips, of a darker material, which is also, in the thermal image, hotter than the clean concrete. These lines are related with the draining of rain water from the crest. One can also notice, in the thermal image, a large hot area on the abutment, parallel to the foundation, area that in the normal photo is dark. Above this one is a yellow/brownish area that has an intermediate temperature.

Other small features on the downstream wall affect the temperature of the surface and for this reason are also visible in the thermal image. The most important is a colder area near the lowest catwalk. In Figure 11 are presented two thermal images of the area (in the second there was an enhancement of the colours made in GIMP, an image manipulation program) and the visible image. In this image, one can noticed that there are some white deposits of carbonates. In these images it is also visible the shade of the catwalk.

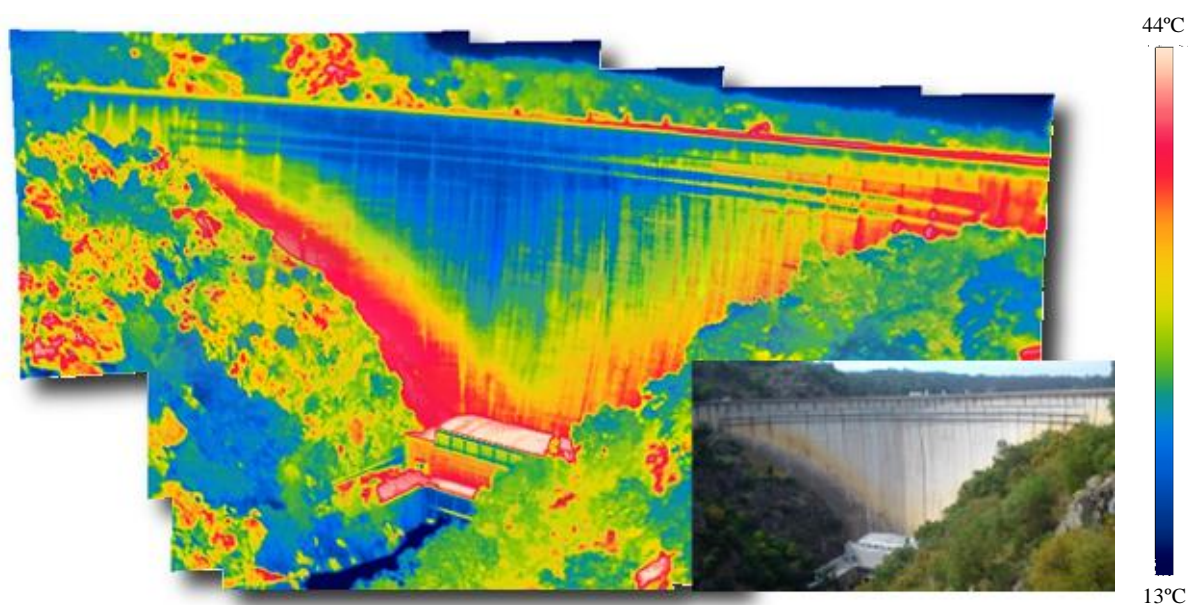


Figure 10: Cabril dam: thermal panoramic image and the normal image.

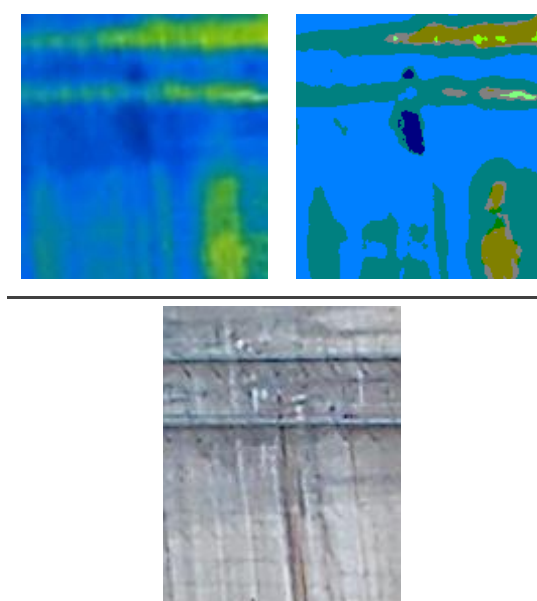


Figure 11: A detail of the thermal image and of the normal image.

### 3.3 Alto Ceira II Dam

Alto Ceira II is also an arch dam, build to substitute Alto Ceira dam. In June of 2013 it was near the end of the construction, being that the first filling started a few days after the 4 of June. As this dam has several thermometers inside the concrete, nine of them a few centimetres from the downstream face (Figure 12), the temperatures measured by these thermometers were used to validate the information gotten from the thermal images. The images used in this evaluation were acquired in front of the dam, near the river (Figures 13 and 14).

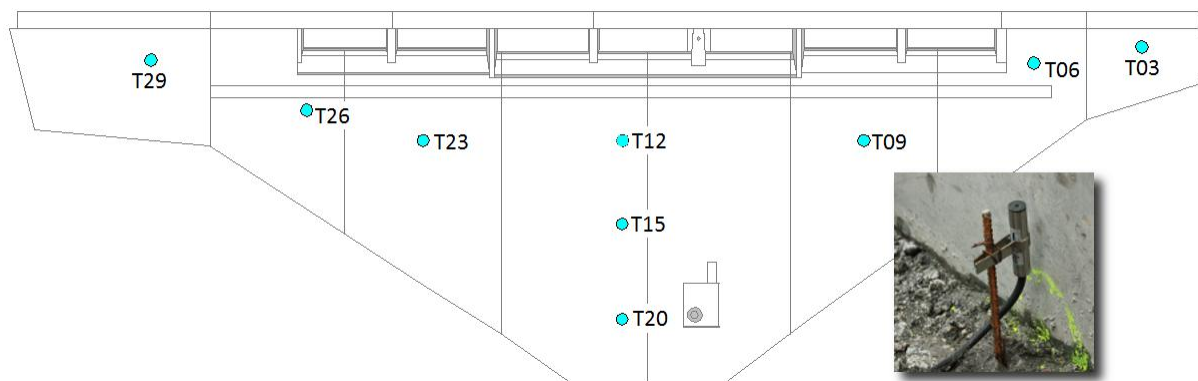


Figure 12: Alto Ceira II dam: location of the nine thermometers near the downstream face. Placement of one thermometer before the concreting.

It was made a careful survey of the downstream face: it was surveyed in 27 minutes (from 12h51min, in T29 area, to 13h24min, T20 area) with 185 images. One of the images is presented in Figure 15. It was also acquired some images (using visible light), as seen in Figure 16.



Figure 13: Camera mounted on the tripod.



Figure 14: Thermal camera.



Figure 15: Thermal image. It includes the chromatic scale.



Figura 16: Visible image of the same area.

Latter all the thermal images were stitched and it was created a panoramic image that, after, was corrected to minimize the distortions (Figure 17).

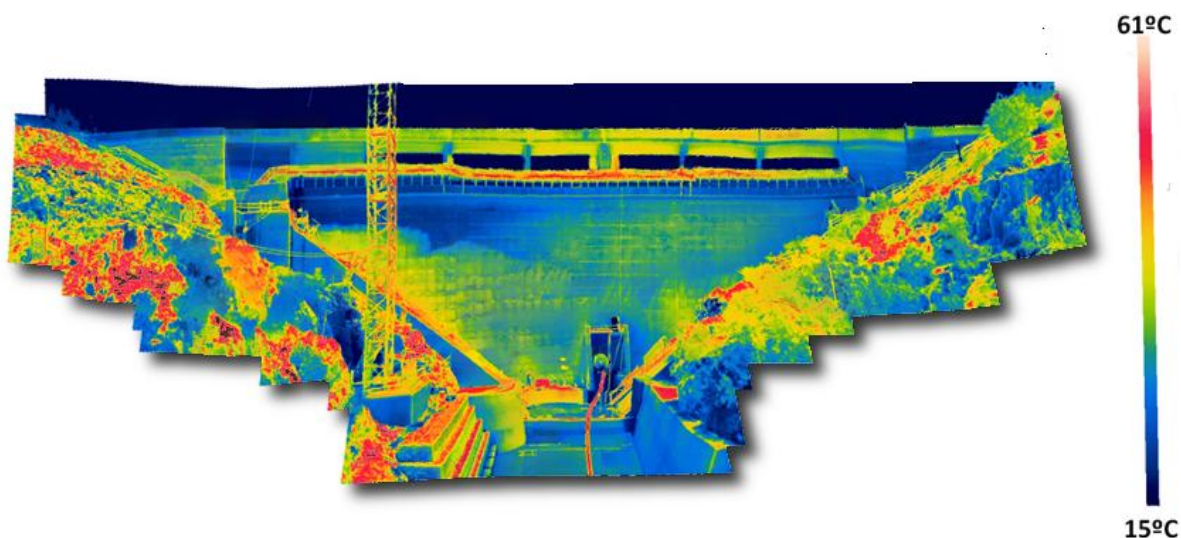


Figure 17: Thermal panoramic image of Alto Ceira II dam.

At the office it was made a comparison between the temperatures from the thermal images and the temperatures measured by the thermometers. For this it were selected the images that included points near those instruments. One of the images selected is presented in Figure 15, since it includes the area near T20; other is the one presented in Figure 19, because it includes the area near T26. In each of those images it was read the temperature in one point, the point nearer the thermometer, using software FLIR ThermaCAM. As there is information about the hour on which the image was acquired it was possible to relate the “thermal image” temperature with the values measured by the thermometers embedded in the concrete since there was also information of the time of these readings. After, it were computed the differences of the temperatures and, for each point, the average of these. The values of the averages are presented graphically in Figure 18. In this Figure is also presented the shaded areas, at two different hours.

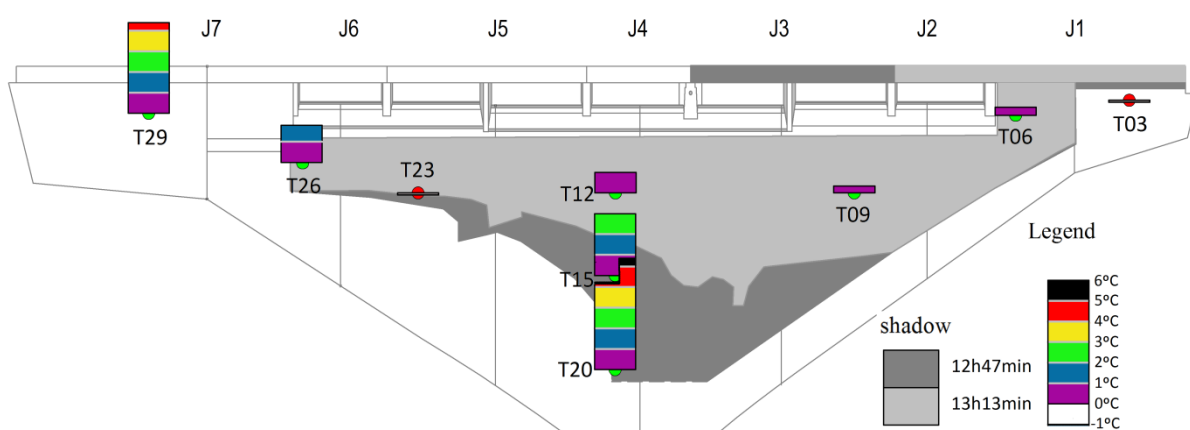


Figure 18: Differences between “thermal image” temperature and “thermometer” temperature.



It is important to remind that each thermometer (a Carlson Resistance Thermometer) is a few centimetres deep and for this, and also because the thermometer has a slow response time (equivalent to the concrete), changes of the temperature of the surface will be sensed by the thermometers some time after the concrete surface has been heated. In fact, with only one exception (on T03), the largest differences happened in the areas where the sun light struck on the downstream face. The small difference detected in T03 area can be explain by the orientation of the wall: not only the sun rays started to strike only 20 minutes prior the photos were taken, but also the angle of incidence was small. On T15 and T20 areas the rays were almost perpendicular to the wall.

Concerning the five thermometers in the shadow, the differences are small, with the exception of T26. But even this one can be explained. Near the area of thermometer T26 was installed a tube to carry water from upstream to downstream, water needed for construction works that were going on near the foundation, on the downstream side. This tube had losses and for this reason some areas of the surface were wet. In Figure 19 one can easily notice these areas because they are cooler, since their colour is dark blue. Some of these areas can't be detected in the visible image, presented in Figure 20. The wet concrete of the surface was cooler and, by heat transfer, the concrete around T26 was also cooler, as can be noticed in the graph of the Figure 19, where the temperature measure by the thermometer T26 is compared with the temperatures measured by other thermometers. In this graph is also included the "air" temperature measured by a thermometer placed a few meters away from the dam.

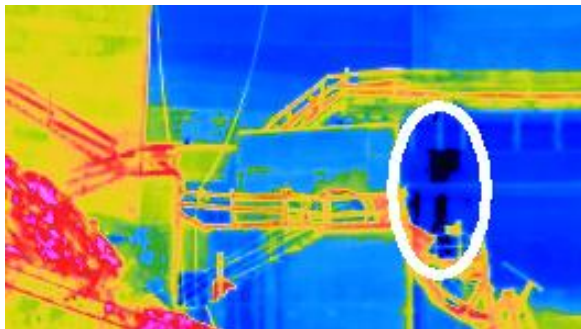


Figure 19: Colder concrete near T26.



Figure 20: Visible image of the same area.

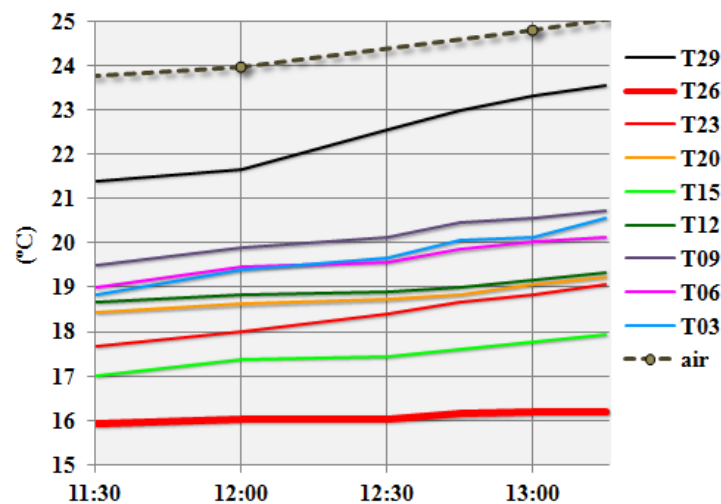


Figure 21: Temperatures measured by the embedded thermometers.

## 4 CONCLUSIONS

The study on the use of thermal images to detect or to follow-up the evolution of pathologies has showed that these can be used to detect the areas with resurgence of water, usually associated with cracks. Thermal imaging cameras, under normal observation conditions, produced instantly accurate images, in which the areas with resurgences are easily recognizable. The thermal survey of the surface of dams was fast: it took a few minutes. The panoramic image, latter produced at the office using software that stitches images, was also fast: it can be produced in less than one hour, by someone with experience.

Since the images are obtained instantly, just like an ordinary visible image, and as they are accurate, is possible to decide during the thermal survey, if there is a need of a more detailed survey, and do it immediately after.

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