MAPPING OF VISUAL DECAY FORMS AND INFRARED IMAGING OF STONE STRUCTURES FOR THE MAINTENANCE AND MONITORING STUDIES

Visual decay and infrared imaging

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Abstract

Well-designed programs are necessary for the efficient maintenance and monitoring studies of stone structures. The mapping of visual decay forms and the infrared imaging of surfaces are useful methods to establish such programs for them. The studies have been performed on the 13th century caravanserai in Aksaray named Agzikarahan. The program started with site investigation by visual analysis of the decay forms on the stone. It involved the visual classification of the observed decay forms and their mapping on measured drawings and drawings produced from rectified photographs. The visual decay forms were classified in groups and each decay form was also evaluated as a degree of damage. The second stage was to take infrared images of the stone surfaces to produce temperature distribution maps which have further been analysed for moisture distribution in the structure. In the light of these studies, sampling has been done for the laboratory analysis. Juxtaposition of the different maps, photographs and infrared images have exhibited the present problems of the structure and their distribution and facilitated to make the immediate and long-term conservation programs.

Keywords: dampness, infrared imaging, maintenance, mapping, monitoring, stone structures, visual decay forms

1 Introduction

The frequency of the problems sourced from the improper or unnecessary maintenance and lack of maintenance show the importance of correct diagnosis of the problems for the maintenance of stone structures. In this respect the correct definition of the present problems of the stone structure and the detailed knowledge about its weathered state are necessary for the maintenance and monitoring studies. The mapping of visual decay forms and surface temperature analyses of stone structures are the two non-destructive and useful survey methods to diagnose their problems which form the first stage of a well-designed research program. (BRE., 1981; Garrecht, 1996; Fitzner et al. 1997, 1996, 1995, 1994; Massari et al. 1993)

Two monuments have been studied for the definition and the diagnosis of the problems. One of them is Agzikarahan, a 13th century caravenserai in Aksaray, Turkey, and the other one is the tomb of Karacabey, a 14th century building in Ankara, Turkey. Agzikarahan has serious problems which can be detected visually, while the tomb of Karacabey has been restored in recent times.

The building stones of the Agzikarahan are tuff, used as cut stone and rubble stone. The characteristic wall structure is cut stone facing on both sides of the wall with rubble stone infill (Altintas). The observations and measurements were made on the tuff cut stone surfaces of the monument.

The site investigation has started with the mapping of visual decay forms as the first stage of the pilot study to prepare the rehabilitation programs for the related buildings. Detailed information were visually recorded on type, intensity and extent of the occuring damages as well as their distribution at the building. The second part of site investigation was the surface temprature analyses together with the infrared imaging of the building surfaces in the context of microclimatic investigations for searching the dampness in the structure. These studies were supported by material sampling and laboratory analysis.

2 Surveys, experiments and their results

2.1 The mapping of visual decay forms

The method developed by Fitzner and others was adopted for the mapping of visual decay forms of stone at Agzikarahan. (Fitzner et al. 1995, 1992) It involved the classification of the visually observed decay forms and their mapping on measured drawings and drawings produced from rectified photographs. The documentation of visual decay forms was done on 1/50 scaled elevation drawings. The decay forms were classified in three main groups such as "stone loss", "stone detachment" and "discoloration and deposits on stone surfaces". Each decay form observed at the monument is classified in the subgroups of these main groups. In addition, each decay form was also given a degree of damage such as "very severe decay", "severe decay", "medium decay" or "slight decay". The observed decay forms and their damage categories are as follows:

- Loss of stone material - most severe and severe decay:
  - Outbursts - most severe decay
  - Outbursts due to the anthropogenic influences - most severe decay
  - Alveolization - severe decay
- Detachment of stone material - medium decay:
  - Scales
  - Flakes

- Discoloration and deposits on stone surfaces - slight decay:
  - White staining
  - White-to-grey staining
  - Grey-to-dark grey staining
  - Black staining
  - Salt deposition
  - Biological colonization

The visual decay forms are analysed in three maps. The first map shows the loss and detachment of stone material and the second one shows the discoloration and deposits on stone surfaces. Furthermore, the areas of new repair stone and original stone are also recorded on the same drawings which is the third map to facilitate the comparison. For instance, Fig.1 is the view of the north elevation at the courtyard and the analysis of decay forms observed on this view was given in Figures 2-4. During the survey period of seven months, the progress of stone decay forms have also been noted.

2.1.1 The results

The results obtained from the mapping of visual decay forms are summarized as follows:

- The most severe decay has been noticed on the original material at the lower parts of the monument up to 130 and 145 cm. height from the ground level as material loss: outburst, together with salt deposits. This situation indicated the existance of continual rising damp problem.
- Severe decay has been observed on the original material at the upper part of the monument as material loss: alveolization, together with lichens. This situation indicated a severe dampness problem at the upper structure which still continues.
- The distribution of new stone material use indicated the previous severe problems related with the upper structure and the lower part of the north elevation walls in the courtyard. Slight decay observed on these new stone surfaces as discoloration with white staining showed that the problems of the monument continue with the upper structure and the lower part of the north elevation walls in the courtyard. Furthermore, during the survey period of seven months, slight decay forms of discoloration in those areas have developed to medium decay forms as flakes and scales. It showed that monument needed urgent interventions.
- The maps also indicated the decay areas where representative sampling can be done for laboratory analysis.

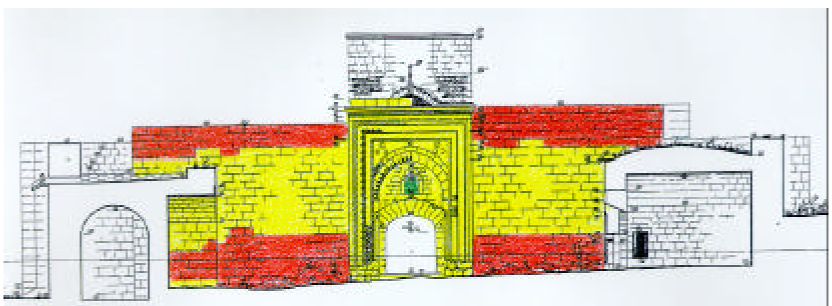
2.2 Surface temperature measurements and infrared imaging of building surfaces

The study of the surface temperatures and the infrared imaging of the building surfaces is the part of the microclimatic investigation of the monument. Therefore, the temperature and humidity measurements were taken from the stone surfaces and in the atmosphere. The instruments used for the study are an infrared thermometer (Raytek Rayngen PM Plus) and a thermovision camera (AGEMA Thermovision 550 camera) for surface temperature measurements, a Gann Hydromette B42 for the moisture content estimation in the material, and a Lambrecht Psychometer Type 761 and Hanna HI 8564 thermo-hygrometer for the relative humidity and temperature measurements of the air next to the stone surface and in the atmosphere.

Although the surface temperature and humidity measurement have been taken for several periods during the four seasons, the infrared imaging of the building surfaces could be taken only once, in May.

The analysis of the studies were done by the comparison of the surface temperature graphics as a function of height on the walls, the infrared images of building surfaces together with humidity measurements, furthermore, by the juxtaposition of the obtained results with the produced maps showing the distribution of visual decay forms.

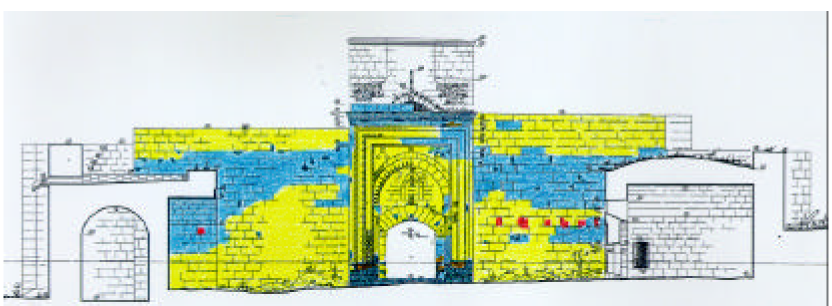
Fig. 1: General view of the north elevation at the courtyard, Agzikarahan



NEW REPAIR STONE

ORIGINAL STONE

Fig. 2: The map showing the areas of new repair stone and original stone



LOSS OF STONE-MOST SEVERE AND SEVERE DECAY

OUTBURSTS-MOST SEVERE DECAY

OUTBURSTS DUE TO ANTHROPOGENIC INFLUENCES-MOST SEVERE DECAY

ALVEOLIZATION-SEVERE DECAY

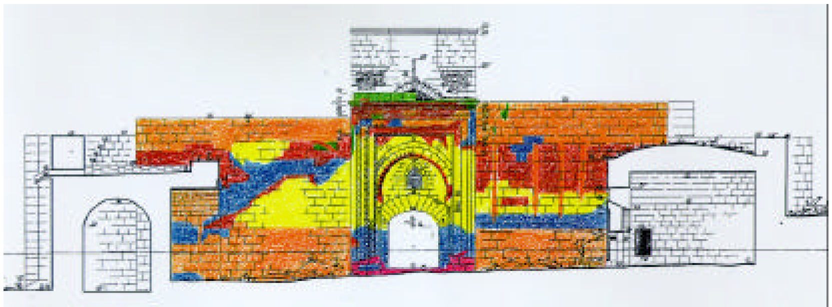
DETACHMENT OF STONE-MEDIUM DECAY

SCALES-MEDIUM DECAY

FLAKES-MEDIUM DECAY

AREAS WITHOUT LOSS AND DETACHMENT OF STONE

Fig. 3: The map showing the areas of loss and detachment of stone material



DISCOLORATION AND DEPOSITS ON STONE SURFACES-SLIGHT DECAY

- **WHITE STAINING**
- **WHITE-TO-GREY STAINING**
- **GREY-TO-DARK GREY STAINING**
- **BLACK STAINING**
- **SALT DEPOSITS**
- **BIOLOGICAL COLONIZATION**

AREAS WITHOUT DISCOLORATION AND DEPOSITS ON STONE SURFACES

Fig. 4: The map showing the areas of discoloration and deposits on stone surfaces

2.2.1 The results

The analysis of these studies have shown that:

- The surface temperature graphics are consistent with the infrared images of the surfaces.
- There is a relationship between the surface temperatures of stones and their decay forms.
- The lower part of the exterior wall surfaces are the coldest areas of the structure. The upper parts of the exterior wall surfaces are the next cold areas. The photograph views and the infrared images of the lower parts and the upper parts of the structure are shown in Figures 5-8.

Fig. 5: Partial view of the south elevation at the courtyard

Fig. 6: Infrared image of the view shown in Fig. 5

Fig. 7: Partial view of the south and west elevation at the courtyard

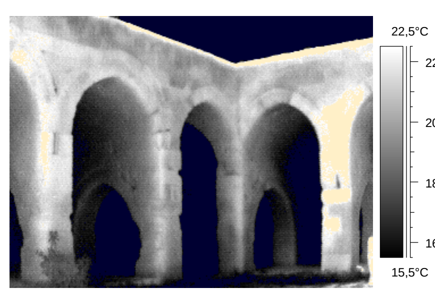


Fig. 8: Infrared image of the view shown in Fig. 7

- The surface temperature increases with the increasing height at the lower parts of building according to the measurement taken in winter. The surface temperatures of the original stone with the most severe decay and severe decay are much colder than the surface temperatures of the new repair stones with slight decay (Fig.9). The moisture content in the original stone is very high, approximately 14%, and the same up to the height of 150 cm., according to humidity measurements taken in January. These results have indicated the presence of rising damp problem.
- In the following seasons the surfaces of the original stone at the lower parts of the building with most severe and severe decay are warmer than the surfaces of new repair stone. The extreme drying must have occurred at the surfaces of the decayed original stone in July and October.(Fig.9).

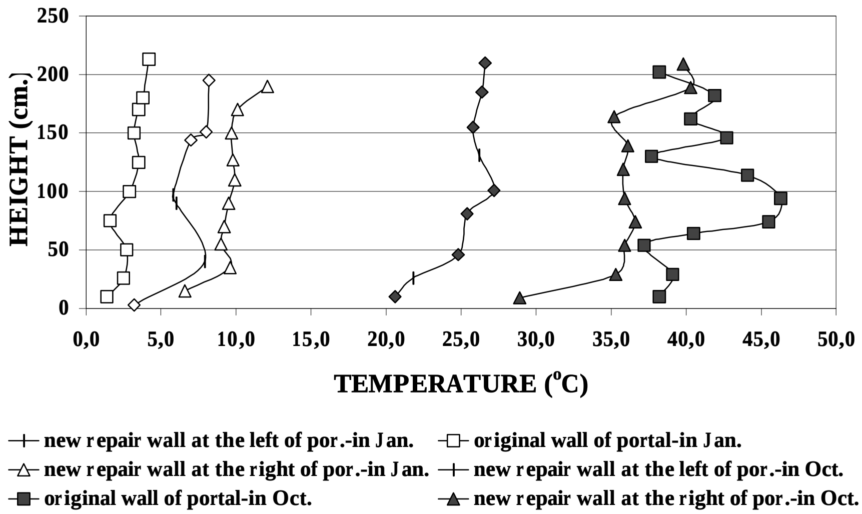


Fig. 9: The surface temperature curves for three region of the north elevation at the courtyard in January and October

- In the rising damp zone, the surface temperature curves of the original stone surfaces having the most severe and severe decays are inconsistent (Fig.10). Extensive salt deposits have been observed on those areas. One of the reasons of the surface temperature fluctuations should be the hygroscopic properties of soluble salts. In addition, the physical properties of the heterogenously decayed stone should be checked.
- The surface temperature curves of the new repair stone with slight decay are more consistent in comparison to the original stones. For instance in Fig.11, the temperature curves have shown that the part of the wall up to approximately 35 cm. height is the coldest area, and the temperature is steady on the wall above this height up to 184 cm. The temperature starts to increase after this level where there is the passage from new repair stone to the original stone. Fig.12 is the view of this region and Fig.13 shows the infrared image of that area which is
- consistent with the temperature curves.

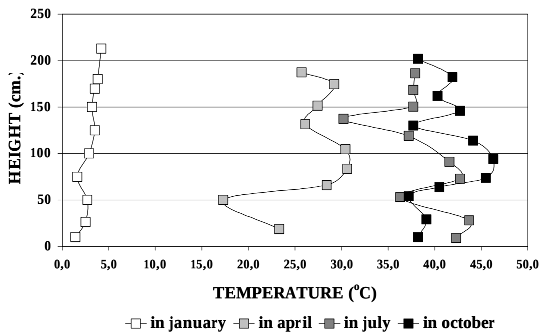


Fig. 10: The surface temperature curves of the original stone at the portal

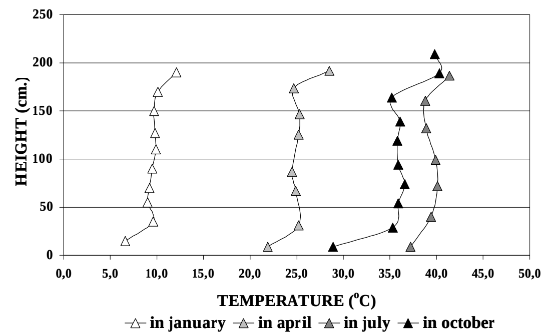


Fig. 11: The surface temperature curves of the new repair stone at the right of the portal

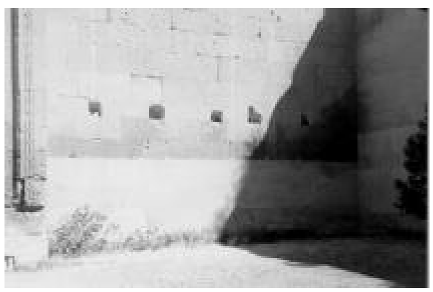


Fig. 12: Partial view of the lower parts from the north elevation at the courtyard

Fig. 13: Infrared image of the view shown in Fig. 12

- the surface condensation is unlikely on the exterior wall surfaces during the investigation times.

  The observations obtained from the infrared imaging studies are as follows:
- The infrared imaging gives the opportunity to analyse an area extensively while surface temperature measurements are restricted with location and time.
- The infrared images have shown that different materials may have different surface temperatures for the same climatic conditions. In A z karahan, there are differences between the surface temperatures of new repair stone and original stone (Fig.8 and Fig.13). The infrared image of the tomb of Karacabey shows that the surface temperatures of mortar, brick and stone are different (Fig.14).
- The infrared images have given information about problem areas on the monument which can not yet be detected by visual analyses. For instance, the infrared image given in the Fig.15, shows that a roof drainage fault has already started in the newly restored monument, the tomb of Karacabey.

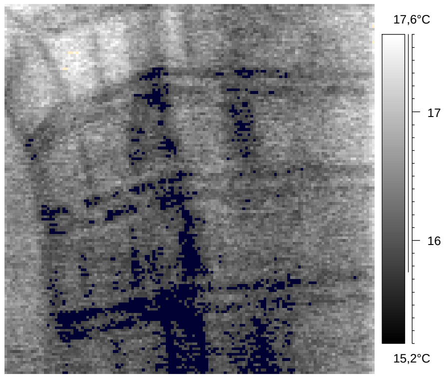


Fig. 14: The infrared image showing different surface temperatures for different materials

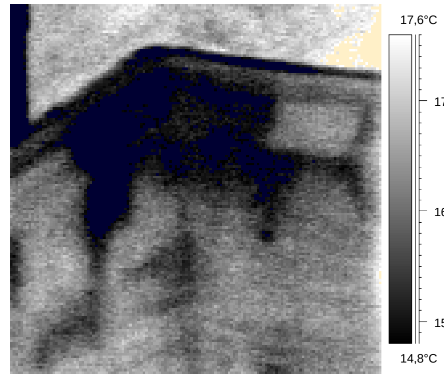


Fig. 15: The infrared image showing a roof drainage fault

- In the times and places where extreme drying occurs, the infrared images can be misleading for the dampness problems. The areas which have mostly suffered from dampness can be seen as dry surfaces in infrared images during a dry summer. Therefore a periodical study is necessary for the infrared imaging of the surfaces supported by temperature measurements.

2.3 Laboratory analysis

In the light of these studies, stone, mortar, salt and soil samples were collected from the decay areas. The laboratory analysis included both the analysis of physical properties of the materials, such as the density, the porosity, and as well as the qualitative and quantitative analysis of soluble salts. (Black 1965; Teutonico 1988) The laboratory analysis have been done to investigate the types of soluble salts, their sources and their relative amounts in the material to verify the importance of salts in the decay. The information obtained from the further laboratory analyses is also necessary for the assessment of the intervention techniques to the materials.

2.3.1 Results of laboratory analysis

The analysis has shown that the density and the porosity values of the original tuff samples are in the range of 1.57 gr./cm^3 -1.70 gr./cm^3, and 27% - 38%, respectively. The density and the porosity of the new repair stone samples are in the range of 1.56 gr./cm^3 - 1.67 gr./cm^3, and 34% - 38%, respectively. Although there is not too much difference between the physical properties of original tuff and new repair stone, the new repair stone is slightly more porous than the original tuff stone.

The quantitative salt analysis have shown that the stone material contains considerable amount of soluble salts in the lower parts and the upper parts of the exterior walls, which are the damp zones.

The amounts of soluble salts in the original stone are in between 3.8%-9.2%. The original stone collected from the most severe and severe decay areas in the rising damp zone are very salty having the salt content of around 7%-8%. The average amount of soluble salts in new repair stone was found 6.0% at rising damp zone. On the other hand, the average amount of soluble salts was found to be 3.5% at the new repair mortar. It is seen that the new repair stone contains more soluble salts than its neighbouring mortar.

The amounts of soluble salts in the new repair stone at roof paraphet walls are in between 3%-8%.

The qualitative salt analysis have shown that the original tuff stone and the new repair stone at rising damp zone contain nitrate, nitirite, sulphate, phosphate and chloride ions in considerable amounts. These types of soluble salts sourced from the soil support the rising damp problem and the presence of ground water has to be checked.(Arnold at al. 1989; Nord et al. 1996; Schaffer 1972) In the new repair stone used at the roof paraphet walls, sulphate, chloride, phosphate and nitrate ions have been found in large amounts. They may come from the deposited soil and plant on stone roof cladding. The presence of sulphate may be due to the use of cement mortar during previous repairs and the effect of air pollution should also be checked.

3 Conclusion

The mapping of visual decay forms and the surface temperature measurements together with the infrared imaging of the building surfaces revealed the types of problems and their distribution in the structure, as well as the extent of damages and their possible sources. The results also help to program the further necessary investigations. The obtained results are as follows:

- Juxtaposition of the produced maps and photographs have shown that the most severe decay was on the original stone at the lower parts of the structure which indicated the continual rising damp problem. The soluble salts were also important decay agents for the structure in damp zones and the presence of soluble salts in the stone supported the rising damp problem. The original field drainage systems have to be invstigated in relation to the periodically produced maps of the structure and the substructure of the building together with the present topography.
- The upper parts of the walls are largely repaired with the new stones which is a sign of previous severe problems in those areas. The slight decay observed on these new repair stones has indicated the continuation of previous problems in the upper structure and roof drainage faults. The results have shown that the study of the original roof drainage system in terms of the materials used, its design principles, its defects, and its capacity is necessary.
- During the periodical mapping, the advancement or the slowing down of the decay can be followed, as well as the changes in the damp zones. The information are very helpful in monitoring studies.

Further non-destructive testing methods, such as ultra-sound velocity testing, are necessary to determine the present condition of the heavily deteriorated stone. The further detailed laboratory analysis are required for the removal of the soluble salts from the stone material, and for the selection of new repair stone and mortar.

These mapping studies supported by the laboratory analysis are the practical and non-destructive site investigation methods which are helpful at each stage of conservation, such as the planning of the the immediate conservation program and the long-term monitoring and maintenance studies.

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