Proc. 11th Int. Cong. on Deterioration and Conservation of Stone, Torun, Sept. 15-20, 2008

TIME-LAPSE MACRO-IMAGING IN THE FIELD: MONITORING RAPID FLAKING OF MAGNESIAN LIMESTONE

E. Doehne[1], S Pinchin[2]
[1] *The Getty Conservation Institute, USA*
[2]*English Heritage, UK*

Abstract

Time-lapse imaging has been used to provide a record of damage to stone as it is occurring in the field. The site of Howden Minster, UK where rapid flaking of Magnesian Limestone has been observed, was used to begin to evaluate the pattern and rate of stone loss, in addition to correlating stone damage with local environmental conditions. Preliminary results indicate that loss is episodic rather than continuous and in some cases is related to unusual environmental conditions, such as high winds. Damage is also synchronous, with surface change occurring at the same time in different stone blocks.

Keywords: time-lapse imaging, erosion rate, digital image analysis, masonry conservation.

1. Introduction

An issue of pressing concern in the conservation of cultural heritage is the general lack of high quality data on rates of change of important art objects, buildings and sites. Fundamentally, conservation is about extending the lifespan of our cultural heritage through intelligent preventive and active interventions. For stone conservation, these interventions, such as routine maintenance (Ashurst and Ashurst, 1988) and efforts to buffer the environment (Viles and Wood, 2007), can act to lower the overall rate of change and material decay. Tools for evaluating effective interventions have increased in number and quality in recent years, such as drilling resistance (Fratini et al., 2006; Rodrigues et al., 2002) and time-lapse methods (Doehne, 2006; Heritage, 1999; Rodriguez-Navarro and Doehne, 1999; Sawdy and Heritage, 2007). Nevertheless, these methods have most often been used in the laboratory rather than the field. Other approaches include recent research on repeat photography (Thornbush and Viles, 2008), quartz crystal resonators to monitor real-time field performance of organic films (Cavicchioli et al., 2008), and a method to evaluate the levels of microbiological activity in the field (Pitzurra et al., 2000).

One of the aims of this work is to bring to the conservation field a low-cost, time-lapse monitoring system for field use using off-the-shelf technology. Adrian Heritage developed the concept of applying annotated time-lapse video methods originally to the study of wall paintings in the mid-1990s (Heritage, 1995). Technology has advanced significantly in the mean time, especially in terms of cost, bulk and computer controls. The digital time-lapse camera system used for this study takes advantage of a new generation of imaging technology designed initially for use as a trail camera for studying animal behaviour. Typically, a standard compact digital camera is mated to a motion sensor with external control electronics and a separate battery pack. The main market for these camera systems are field biologists and deer hunters resulting in a wide range in capability and price, although many lack a time-lapse mode.

In our case, we were able to convince one manufacturer to add an interval timer for time-lapse imaging and optional external flash. This custom unit is now available on the open market, mounted in a rugged Pelican case for a few hundred euros (CamTrak, 2008). The specifications for the system used in the current study include a seven megapixel camera capable of interval macro photography and of operating unattended for three months for use at remote sites. This makes it a useful method to evaluate material decay mechanisms in the field and their still poorly understood relationship to fluctuations in environmental conditions.

An important question in stone conservation is whether material damage takes place as continual process or an episodic event. In other words, does damage take place due to an accumulation of everyday environmental stress or is most damage caused by relatively rare extreme environmental changes? Answering this question has important implications for preventive conservation strategies. For example, some types of rare events may be more easily mitigated by efforts to buffer environmental extremes such as thermal stress (Viles and Wood, 2007). This is precisely what English Heritage and the Getty Conservation Institute are trying to achieve at the site of Howden Minster, a 14th century ruin located in East Yorkshire, England, where the magnesian limestone is suffering from severe flaking (Pinchin et al., 2008)(Fig. 1).

Figure 1. Figure 1a,b, c. Howden Minster ruin, chapter house (ca. 1388), and nearby Drax, the second largest coal-fired power station in Europe.

The site is located 27 km south-east of York and 7 km downwind from Drax, a large coal-fired powerplant. Annual macro photography of the stone over a three-year period had demonstrated the creation of new flakes and the loss of existing flakes (Fig. 2), yet the degradation mechanism needed further examination in order to answer the questions posed above. To determine the relationship between damage rates – frequency and amplitude of damage over time – and environmental conditions, a time-lapse camera was installed, followed by an environmental monitoring system. The environmental monitoring system is discussed elsewhere (Pinchin et al., 2008) and the camera system and results are the focus here.

2. Materials and Methods

Our field time-lapse system is composed of a standard seven-megapixel compact digital camera (Sony DSC W-7; 7.18 x 5.32 mm CCD sensor) with a four-gigabyte memory card in a small, insulated Pelican case (Camtrakker® trail-camera, CamTrak South, 1050 Industrial Drive, Watkinsville, GA 30677, (706) 769-4025). The equipment used is not prohibitively expensive, however there are limitations to the protection of equipment on unmanned sites. The camera was placed near a stairwell that has suffered rapid stone loss (Fig. 3) about a meter from the stone to ensure three pixels per millimeter resolution in the field of view. Using a lead acid battery to power the time-lapse circuitry and a lithium battery to power the camera allowed three months worth of full resolution images to be acquired at three-hour intervals. Processing the data involved three steps: the images were colour corrected using the *Match Colour* command in *Adobe Photoshop* to normalize for some exposure and lighting variations. Then the images are compiled into a high definition movie format using Apple QuickTime software that facilitated immediate visual detection of even small losses of stone, when alternating rapidly back and forth between two images, similar to the blink comparator detector used by astronomers to find comets (Kuhn et al., 2007; Wilcox and Cooke, 1990). Areas of surface change (typically millimeter-scale loss of surface from granular disintegration and flaking) were quantified in Photoshop by manually selecting the area.

3. Results

Preliminary results from time-lapse photographic data show that the loss of stone flakes and the creation of new ones at Howden is an episodic, rather than a continuous process. For the period covering April and May of 2007 most days go by with no activity recorded, followed by a brief period recording several areas of activity–either loss of flakes or creation of new ones. For example, two events where rapid change were recorded occurred on May 8 and May 15, 2007 (Fig 5a, b; Fig 6a, b). The area of surface change involved in the events of Fig. 5 is 0.007% of the total image area, showing that most of the stone was stable. In several cases, water droplets appear to be condensing on the lens of the camera prior to damage events, suggesting that condensation may play a larger role in stone damage at Howden than previously anticipated.

The results presented here address the concern expressed by Zehnder (2007) that there might be short-term cycles of damage missed because of resolution limitations in conventional methods of monitoring damage.

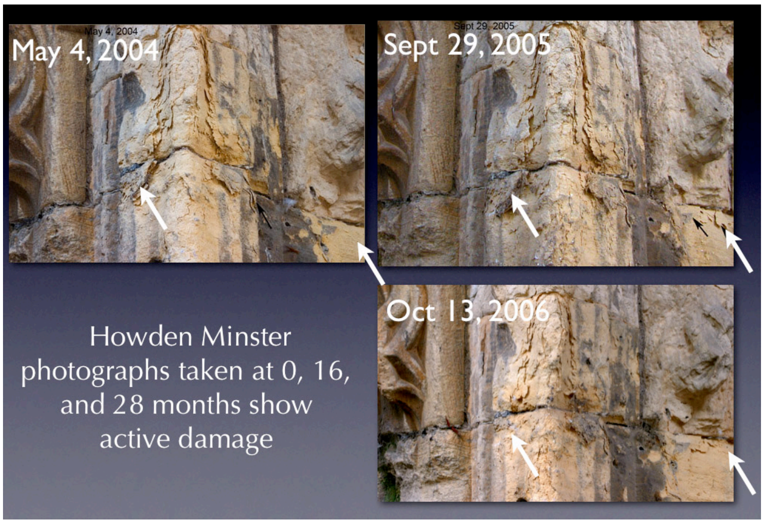

Figure 2. Results from repeat photography showing the creation of new flakes and the loss of old flakes over a period of 28 months documents active damage to Magnesian Limestone.

Previous efforts to measure damage in real-time have typically involved examining weight changes in fallen debris collected either at the base of a wall on site, or on a sample in the laboratory exposed to changing humidity levels (von Konow, 2001; von Konow, 2002). The inherent flaw of this system was that measurements were affected by surrounding conditions, as increasing humidity increased the hygroscopic moisture in the debris on the scale even in the absence of additional flaking. We found that the field time-lapse camera has several advantages: it allows the formation of new flakes, the time of the production and loss of existing flakes to be accurately monitored on site with a simple, reproducible system.

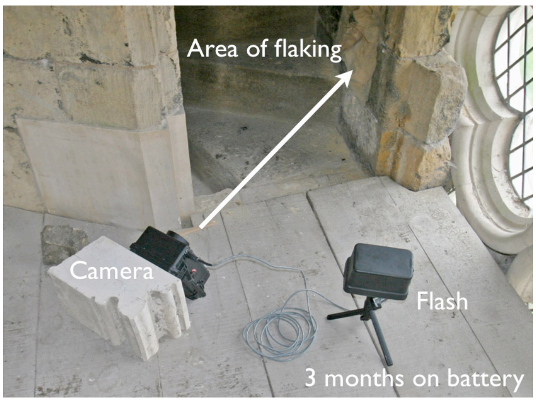

Figure 3. Field time-lapse experimental setup at Howden Minster in stairwell area.

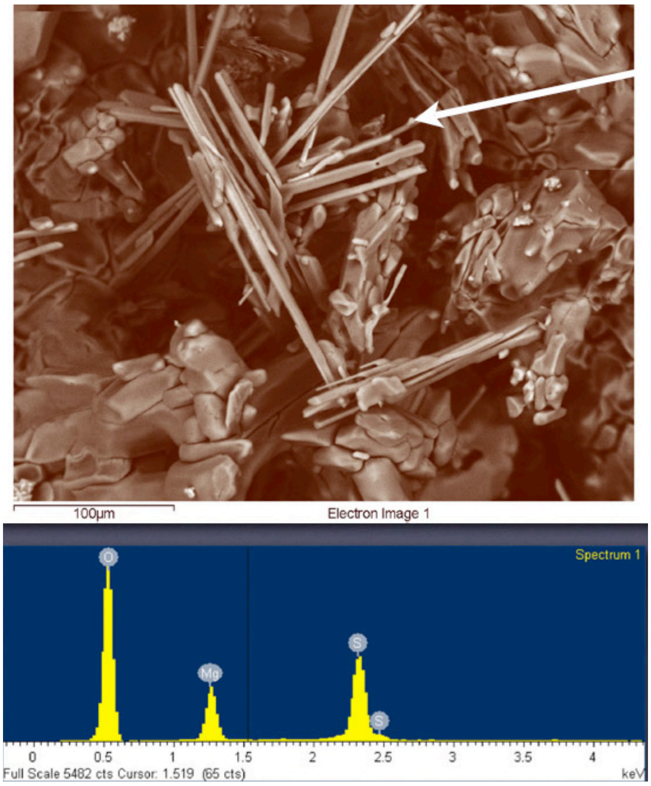

Figure 4. ESEM/EDS analysis of salt efflorescence associated with flakes removed from stone surface showing predominately Magnesium Sulfate.

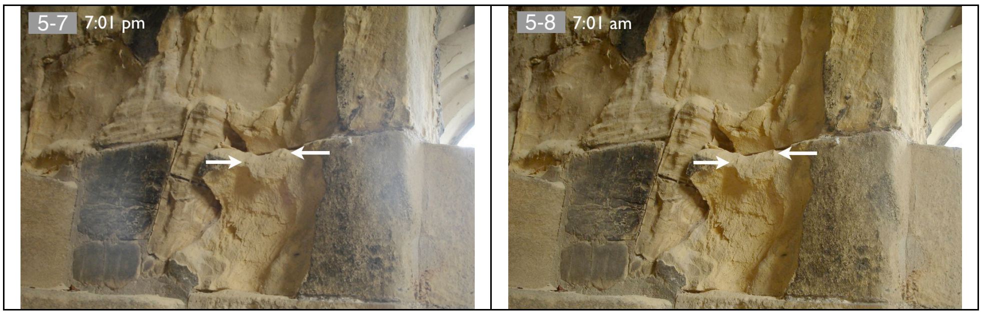

Figure 5. Two time-lapse images showing an episodic loss event on May 8, 2006 with loss of stone surface taking place at white arrows.

Figure 6. Two time-lapse images showing the episodic loss event seven days later than in Figure 5 with new losses taking place at white arrows (May 15, 2007).

4. Discussion

The usefulness of this information is clear once it is processed into video form where the differences between the sequential images are easily identified by the human visual system (Kuhn et al., 2007). Episodic damage is a common pattern of stone decay. It has been discussed by Goudie (1995), Smith (2002), and Roberts (2005). Viles (2005) even suggests that some weathering losses may follow a chaotic pattern.

One question not originally posed, but interesting nonetheless is if damage in different stones is synchronous? In other words, does the damage occurring within the field of view of the camera take place at the same time, or does it depend on the variations in the stone, or is it simply random? Observations at Howden thus far show that the damage only affects a small portion of the field of view, but the damage that does occur is indeed synchronous. That is, it occurs over a discrete interval of a few hours in different parts of the field of view that are separated by tens of centimeters and in several cases are on different blocks of stone. Therefore, this may suggest that the dominant factors in damage at this site are a combination of environmental condition and local salt concentration, rather than inherent vice or variation in the substrate.

In the case of the damage observed on May 8, 2007 a check of the University of York weather database shows high winds in the area on this date, with a maximum wind speed of 34.7 mph in York. The lack of a weather station at Howden itself limits this comparison and a weather station has now been installed at the site. At least a year's worth of image and climate data is needed to better correlate the stone surfaces losses with microclimate patterns. The fact that some loss events correlate with high winds, may indicate a correlation with increase drying rates and thus salt solution supersaturation in sheltered areas (Espinosa Marzal and Scherer, 2008; Genkinger and Putnis, 2007; Rodriguez-Navarro and Doehne, 1999). It should be noted that the stairwell site at Howden is well sheltered from rain, however the stairwell acts as a venturi , especially in windy conditions.

5. Conclusions and Future Work

This work demonstrates the usefulness of field time-lapse imaging of surfaces to economically monitor stone decay on the millimetre scale. Preliminary data suggests that the damage at Howden Minster is episodic, synchronous and related to environmental events such as high winds and condensation. Future work will include testing of a stereo system with two cameras for better depth perception, upgrading the system to email photographs using cellular, Wi-Fi or WiMAX technology, as well as placing cameras at other sites with similar rapid rates of decay to see if the preliminary results gathered at Howden reflect a general pattern or are an exception.

6. Acknowledgements

This work was undertaken within the frame of a joint project between English Heritage and The Getty Conservation Institute on the conservation of Magensian Limestone. We acknowledge the support and advice of Jeanne Marie Teutonico, Giacomo Chiari, John Fidler, William Martin, and Chris Wood in this research. Special thanks to David Odgers and Tobit Curteis for their contributions to this research.

7. References

Ashurst, J. and N. Ashurst, eds., 1988. Practical building conservation. Vol. 1: stone masonry: Title of Series: English Heritage Technical Handbook. Gower Technical Press, Gower Technical Press.

CamTrak, S., 2008. CamTrakker Environmental Unit, http://www.camtrakker.com/mk-8-environmental.aspx.

Cavicchioli, A., D.L.c.A.j. de Faria, C.A. Neves*, et al.*, 2008. Automatic devices for monitoring environmentally induced auto-oxidative degradation of artistic materials in conservation sites. Sensors and Actuators B: Chemical 131, 462-469.

Doehne, E., 2006. ESEM Applications: From Cultural Heritage Conservation to Nano-Behaviour. Microchimica Acta 155, 45-50.

Espinosa Marzal, R.M. and G.W. Scherer, 2008. Study of salt crystallization in limestone with DMA and DSC Environmental Geology http://dx.doi.org/10.1007/s00254-008-1441-7.

Fratini, F., S. Rescic and P. Tiano, 2006. A new portable system for determining the state of conservation of monumental stones. Materials and Structures 39, 139-147.

Genkinger, S. and A. Putnis, 2007. Crystallisation of sodium sulfate: supersaturation and metastable phases. Environmental Geology 52, 329-337.

Goudie, A., 1995. The Changing Earth: Rates of Geomorphological Processes (The Natural Environment). Blackwell Pub.

Heritage, A., 1995. Imaging dynamic processes in conservation; time-lapse video microscopy and on-line date annotation. MA thesis, Courtauld Institute of Art, University of London.

Heritage, A., 1999. Imaging dynamic processes in conservation: on-line data acquisition and direct image annotation, Proceedings of the 6th International Conference on "Non-destructive Testing and Microanalysis for the Diagnostics and Conservation of the Cultural and Environmental Heritage. Rome, 297-310.

Kuhn, A.R., J.A. Klein, W.R. Stevens*, et al.*, 2007. The digital blink comparison technique as a diagnostic aid for medical imaging. Computer-Assisted Radiology and Surgery 2, S62-S64

Pinchin, S.E., T. Curteis, D. Odgers*, et al.*, 2008. Understanding the Decay of 14th Century Magnesian Limestone Carvings in Yorkshire, UK. Art2008. City.

Pitzurra, L., M. Giraldi, G. Sbaraglia*, et al.*, 2000. Microbial environmental monitoring of stone cultural heritage, Proceedings of the 9th International Congress on Deterioration and Conservation of Stone. Amsterdam, Elsevier Science B.V., 483-491.

Roberts, S.M., 2005. Surface-recession weathering of marble tombstones: New field data and constraints. Special Paper 390: Stone Decay in the Architectural Environment 390, 27-37.

Rodrigues, J.D., A.F. Pinto and D.R. da Costa, 2002. Tracing of decay profiles and evaluation of stone treatments by means of microdrilling techniques. Journal of Cultural Heritage 3, 117-125.

Rodriguez-Navarro, C. and E. Doehne, 1999. Salt weathering: influence of evaporation rate, supersaturation and crystallization pattern. Earth Surface Processes and Landforms 24, 191-209.

Sawdy, A. and A. Heritage, 2007. Evaluating the influence of mixture composition on the kinetics of salt damage in wall paintings using time lapse video imaging with direct data annotation. Environmental Geology 52, 303-315.

Smith, B.J., J.J. McAlister, J. Meneely*, et al.*, 2002. Modelling the rapid retreat of building sandstones: A case study from a polluted maritime environment. Geological Society Special Publication, 347-362.

Thornbush, M. and H. Viles, 2008. Photographic monitoring of soiling and decay of roadside walls in central Oxford, England. Environmental Geology.

Viles, H.A., 2005. Can stone decay be chaotic? Special Paper 390: Stone Decay in the Architectural Environment 390, 11-16.

Viles, H.A. and C. Wood, 2007. Green walls?: Integrated laboratory and field testing of the effectiveness of soft wall capping in conserving ruins, Geological Society Special Publication 271, Building Stone Decay: From Diagnosis to Conservation, p. 309-322.

von Konow, T., 2001. Mechanisms of brick deterioration due to salts: New results on salt behaviour from in-situ studies at the Suomenlinna fortress in Finland. Internationale Zeitschrift für Bauinstandsetzen und Baudenkmalpflege = International Journal for Restoration of Buildings and Monuments 7, 675.

von Konow, T., ed., 2002. The Study of Salt Deterioration Mechanisms - Decay of Brick Walls influenced by interior Climate Changes. Helsinki, Finland, European Heritage Laboratories, Raphaël 1999, The Governing body of Suomenlinna, 141 p.

Wilcox, A.J. and W.J. Cooke, 1990. Automatic search and detection of comets and asteroids. Proceedings of SPIE - The International Society for Optical Engineering, 160-164. City.

Zehnder, K., 2007. Long-term monitoring of wall paintings affected by soluble salts. Environmental Geology 52, 353-367.