Spatial and Temporal Visualization of AAR Evolution; Cooling Tower Example

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This White Paper addresses the challenges of monitoring and projecting measured complicated spatial and temporal data (such as AAR expansion, concrete compressive strength, temperature, or any other quantity) in structures of different shapes and offers an innovative solution to remedy the absence of convenient and effective methods of organizing, interpreting and visualizing measurements. Innovative techniques based on Kriging analysis and ParaView visualization software are used to obtain surface maps from point measurements.

1 Introduction

Alkali Aggregate Reaction (AAR) is an irreversible damage that can affect major concrete structures. Whereas early signs may not be of immediate concern, the damage may eventually sufficiently jeopardize the structure's integrity to the point that allowable thresholds are exceeded.

Given the requirements to maintain plant safety and operability, one is left with critical fundamental questions: how to best to monitor and assess the extent of progressive damage, how seriously impacted is the structure, and when (and how) can decisions be made concerning structural integrity and safety?

This white paper seeks to provide answers to these questions by identifying the three major challenges:

Dammage Mapping For a number of reasons, we typically record damage at a limited number of locations. This beg the question: What is the sate of damage in-between those specific locations?

Damage Visualization Based on damage visualization, how can we identify regions where more data are needed for a more complete damage assessment?

Damage Measurement Guidance Based on damage visualization, how can we identify regions where more data are needed for a more complete damage assessment?

I shall address each of those two challenges separately (though they are tightly interconnected).

2 Damage Mapping

2.1 Detection

Broadly speaking, there are three levels of damage detection and quantification (Courtois et al., 2021):

Visual inspection of surface cracks[1].
Crack index: Surface visual inspection of cracks.
Expansion measurements: Internal (mostly) close to the surface. Those measurements are taken once the crack index has reached a critical value.
Others: such as photogrammetry and LIDAR (Salamon, Dressel, and Liechty, 2021).

These measurements are made at different location (spatial), and at different times (temporal).

2.2 Mapping

Measurements are point-wise, and they are certainly not singular points but a reflection of a field if deterioration surrounding it. Hence the question is how do we go from point data to surface/volume data (i.e. continuous data from discrete point measurements)?

Geostatistics (modeling uncertainty associated with spatial estimation) would constitute a mathematical framework to address this problem. It is the generic name for a family of techniques which are used for mapping measurements from limited sample data and the estimation of values at unsampled locations.

If two locations, i and j, are close to each other in terms of the distance, we will expect their corresponding measurements to be similar and have a large covariance. As the points get farther apart, they become less similar, and the difference in the measurements will become larger, and the covariance decreases. Fig. 1 is a commonly used covariance function for a two dimensional field (Saouma, Hariri-Ardebili, and Graham-Brady, 2020). In our case, a method of choice would be Kriging[2] which interpolates the value of a measurement at an unobserved location from observations of its value at nearby locations.

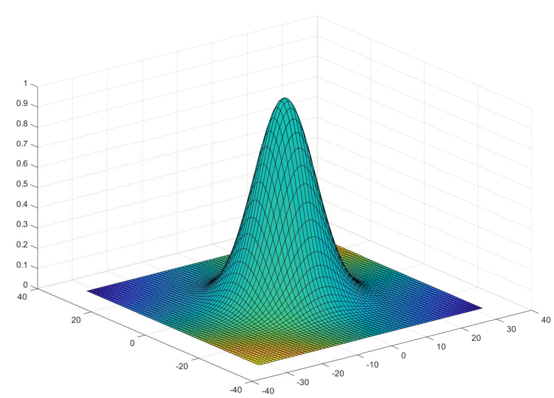

Figure 1: *Example of a co-variance function with a characteristic length of 10*

The method is extensively used in mining, geology, environmental science, mapping and others.

A word of caution, Kriging is more successful when directional bias or spatially correlated distance is present in the data.

2.3 Examples

An example of Kriging is shown in Fig. 2. Measurements were made at the locations marked with a black dots, and field values were determined based on their values.

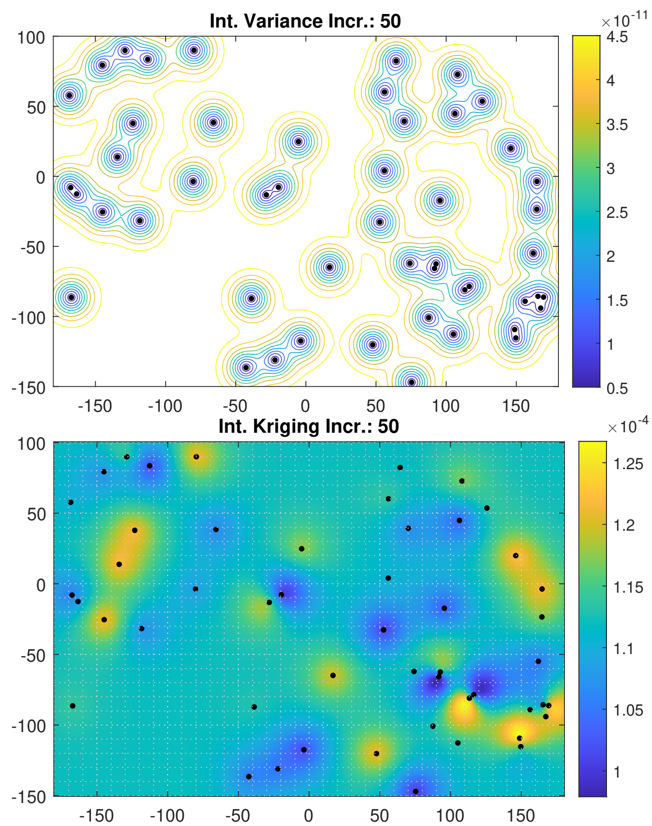

Figure 2: *Variance and resulting Kriging*

2.4 Data Visualization

Visualization of spatial data is a challenge. For the most part, Engineers have (over)relied on simple plots of data detached from the structure from which they were recorded. A simple example would be a plot of expansion at location i in terms of time.

[1]Careful, since AAR thrive in high relative humidity (i.e. inside the surface), a surface (where typically the RH is lower) crack is a manifestation of a potentially more severe internal one. Hence, is many cases detection of a surface crack may be "too late".

[2]Kriging is a technique to predict the value of a function at a given point by computing a weighted average of the known values of the function in the neighborhood of the point. Simple explanatory video here.

Alternatively, one could treat the collected data in analogous way we visualize results from a 3D finite element analysis; i.e. plot the structure (cooling tower in our case), and color shade on the basis of damage. Which software would be best suited to solve this problem?

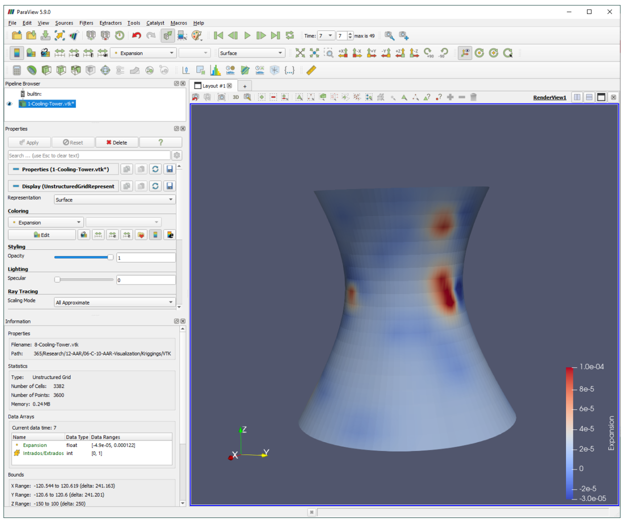

Figure 3: *Example of the graphical user interface*

I strongly advocate using paraview which is possibly the best one to perform data analysis and visualization (Ahrens, Geveci, and Law, 2005). It is a multiple platform software developed by Kitware (development was supported by Sandia National Laboratory and the Los Alamos National Laboratory) and is widely used in scientific circles. This same software can be conveniently be adapted to visualize other parameters such as thermal mapping, concrete compressive strength or others.

2.5 Damage Measurement Guidance

Data clustering is more easily visualized with the proposed method. Because the extent of damage is color-coded on the surface, critical regions are quickly identified. Highlighting the damaged regions can lead the analyst to realize that further data gathering in selected damaged areas is prudent and that further modeling may be needed.

3 Kriging and Visualization of AAR in a Cooling Tower

For illustrative purposes, a ParaView model was built for a (fictitious) cooling tower undergoing AAR damage with time. Random number generators were used to locate sensors (placed in "hot spots" where AAR may have been noticed for the first time), and for the rate of evolution.

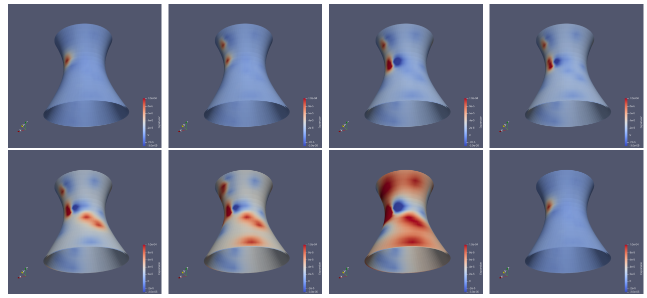

Figure 4: *Visualization of damage evolution with time*

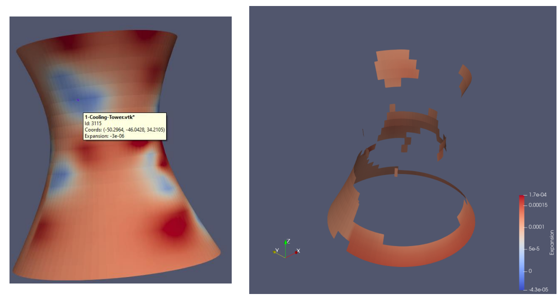

Figure 5: *Hovering the mouse to determine expansion at various points and Threshold*

Expansion is capped at 1.2%. Fig. 4 shows the evolution of AAR expansion at different time increments.

The user can point the mouse to a point of interest, or select a range of values of interest (all other points will be deleted from the rendering) Fig. 5.

Contour lines to identify zones of large expansion as well as clipping are possible, Fig. 6 We can select a point, and plot its expansion over time, or plot a histogram of damages throughout the structure, as in Fig. 7. And much more.

4 Unsolicited Proposal

We believe that the utilization of such a visualization software is a valuable tool for monitoring and assessing AAR progression. C-10, through its consultant Prof. Saouma, would be willing to undertake the development of this software for the NRC and NextEra which enables more effective visualization of the expansion data for the AAR

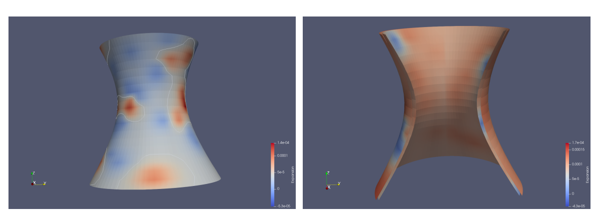

Figure 6: *Contour lines and Clipping*

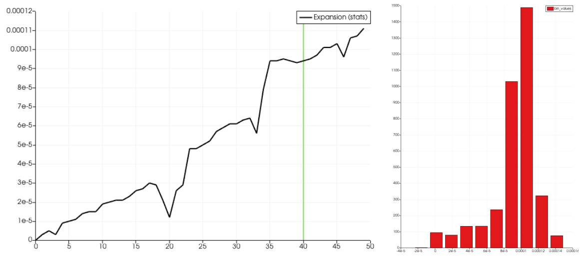

Figure 7: *Temporal evolution of a user specified point; Histogram of expansions*

impacted structures within the Seabrook nuclear power plant. This proposed solution proves itself as a more comprehensive approach to data management and AAR damage mitigation.

To use the software, the NRC and NextEra need simply to provide details of the geometry, location of the gages, and the dates and measurements at each gage. Excel file formats would be ideal. ParaView is an OpenSource Software, hence there is no cost to use it.

References

Ahrens, James, Berk Geveci, and Charles Law (2005). "Paraview: An end-user tool for large data visualization". In: *The visualization handbook* 717.8.

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