Effects of algae on monuments in hot and humid climates

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Introduction

Since the historical building and monuments are under hot and humid climates, most of them suffer from the growth of plants and microorganisms such as algae on their surfaces which cause a change of their appearance or deterioration of the materials (Chiraporn, 1999).
This is a quite serious problem in preserving the cultural properties because they have significant influences on the material characteristics and appearance.
It seems effective to predict the state of the properties in future and evaluate the alternative measures before any treatments are taken.

Purpose of this study

- In this study, focusing the influences of plants and microorganisms on the stone monuments,

  we propose a prediction model of the algae growth under various environmental conditions for preservation purposes.

  The Great Buddha in Sukhothai was investigated in this study.

Wat Sri-Chum

- Temple:
- 24m x 24m x 14.5m. Wall are made of 3m thick brick. There is no roof.
- Great Buddha Statue: 15m high

In 1998, cleaning of the surface and the hydrophobic treatment by silicone paste were made since surface of the Buddha Statue was covered with moss, algae and so on. The blackening of the surface due to the algae was observed again from around 2001. Then, the area of algae growth is increasing.

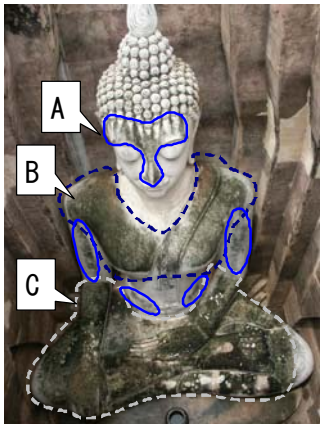
Characteristics of the algae on the Buddha surface

From observing them and investigating photos, we categorized three areas; A,B and C.

A) Vertical surface such as forehead, arms and concave area in the abdomen: no direct rain, but water (rain) flow from upper areas.

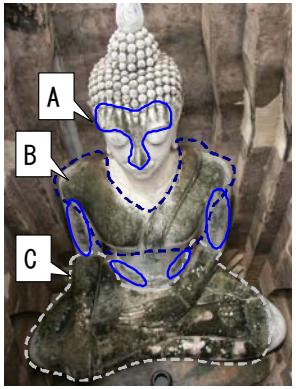
B) Sloped surface area: directly attacked by the rain although the rain flows away and there is a lot of solar radiation areas where a lot of water is retained.

C) Surface facing upwards: directly attacked by rain or water flowed from upper areas, although with strong sunshine areas where water can be retained without flowing away.



Characteristics of the algae on the Buddha surface (2)

- On the other hand, the areas where the algae hardly grows are; the upper part of the head that is attacked by rain but easy to be dried by the strong solar radiation, or the vertical surface areas without direct rain such as neck, lower breast, areas between arms and waist.



The conditions for the algae growth

Therefore, the conditions for the algae growth can be summarized as follows.

- a) a lot of water supply,
- b) a lot of water retained, not easy to be dried,
- c) sufficient radiation for photosynthesis.

That is, whether the algae grow or not appears strongly dependent on the amount of water supply and capacity of water storage.

The solar radiation has both effect, promoting growth (photosynthesis) and suppressing growth (water evaporation and overheating).

Algae growth model incorporating environment microclimate

- The amount of water on the surface where the algae live influences their growth rate
- Prediction of the growth of algae is needed to predict sequentially moisture content of the algae

Modeling of algae growth

- The algae growth rate is influenced by solar radiation, temperature and moisture content
- Population density of algae **N** is assumed to be proportional to the present density **N**

$$\frac{dN}{dt} = Gr_0 \cdot N$$

N: population density of algae [1/m^2], t: time[s],
G: integrated environmental index[-]
r_0: growth rate when G=1 [1/s]

Integrated environmental index G

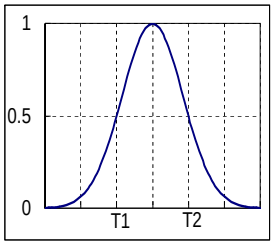
- G: The fitness of the algae to the environment
  A function of the temperature, moisture content of the algae and the solar radiation incident on the algae

$$G = g_T \cdot g_W \cdot \{G_0 + (1-G_0)\, g_S\}$$

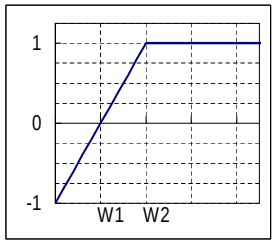
- G_0: value of G when g_T, g_W =1 and g_S =0
- g_T, g_W, g_S: environmental indexes
- g_s : The environmental index related to solar radiation
  Fitness only to the photosynthesis
- G =−0.05 if g_S =0 continues for 7 days.

Environmental index g_T、g_W、g_S

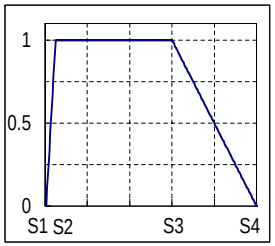
- $T_1, T_2, W_1, W_2, S_1 - S_4$: ,Parameters.
  Their values are determined so that a good agreement can be obtained between the observed and calculated growth rates



Temperature g_T



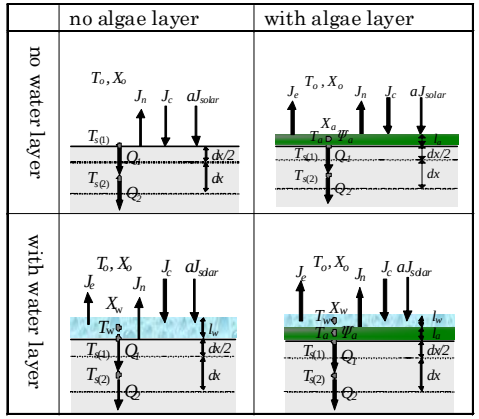
Moisture g_W



Solar radiation g_S

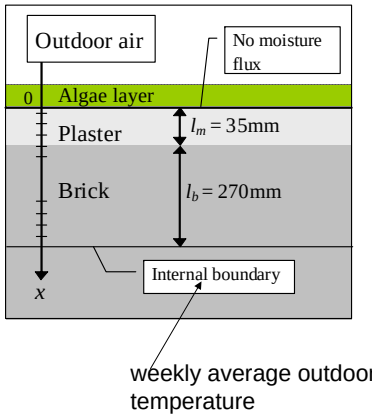
Analytical model

Heat and moisture conservation are taken into account the algae layer and water layer in each process



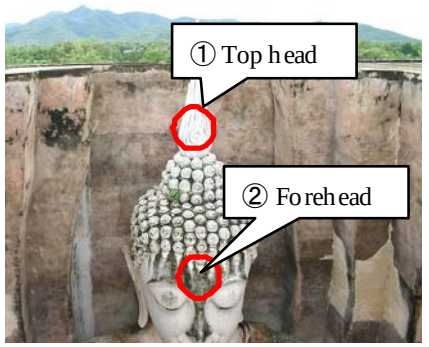
Analysis object and calculation

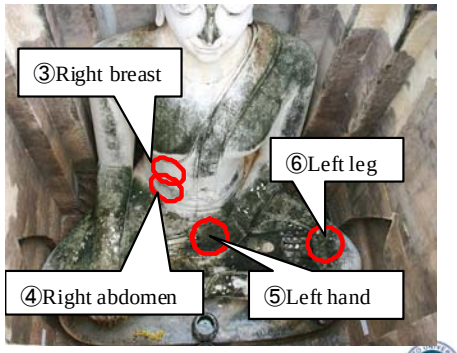
- Analysis object:
  1 dimensional
- Calculation:
  Explicit finite difference method



Areas analyzed

- Initial condition: the starting time when the surface of the Buddha was cleaned in 1998
- Six areas on the surface with different algae population densities were selected and analyzed



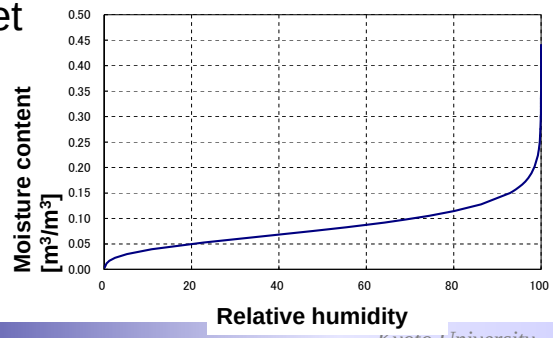


Input conditions and used properties

- Input conditions
- Annual temperature and humidity measured at the right window and the solar radiation observed on the top of the roof were used repeatedly.
- Precipitation on each area was determined by *Rain* multiplied by the factor, which takes into account the heaviness of the rain attack to the area.

Moisture property of algae

- The sorption isotherm of the Sandy Clay Loam was used instead of that of the algae because the data of the algae is not obtained yet



Comparison between observed and calculated results

- First, the simulation for 9 years was carried out to three areas; ① top head, ④ right abdomen and ⑤ left hand. As a result, optimal parameters are obtained from these analysis
- The population density of algae was estimated from the photos from the cleaning time to the present
- The photos from 2002 to 2005 were converted to the grey scale. The brightest area on the Buddha surface is given point 0 while darkest area is evaluated as point 1.

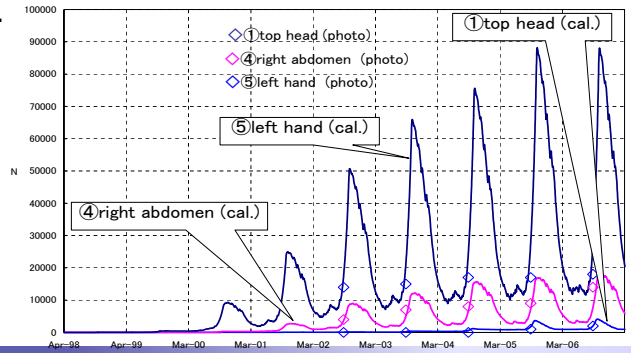
Determination of parameter values in algae growth model

- The values of several parameters such as environmental indexes were determined so that a good agreement between the observed and the calculated *N* values can be obtained.

N_0	1	W_1	0.15	S_1	5
R_0	0.0026	W_2	0.4	S_2	50
G_0	0.5	T_1	15	S_3	600
		T_2	35	S_4	1000

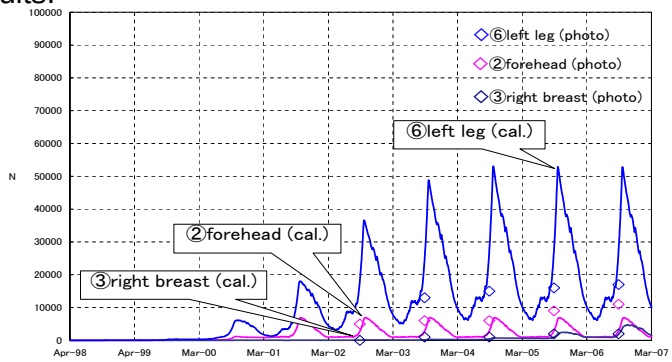
Comparison between observed and calculated results

The value of *N* starts to increase in June arriving at its peak in early November, then decreases. This result corresponds to a water supply, that is, an increase in the density during rainy season and a decrease during dry season.



Comparison of results regarding the other areas

- A similar simulation for 9 years was done concerning the other areas, ②forehead, ③lower part of right breast and ⑥left leg, by using the optimized values of the parameters in the previous analysis.
- The calculated growth rate agrees well with the observed results.

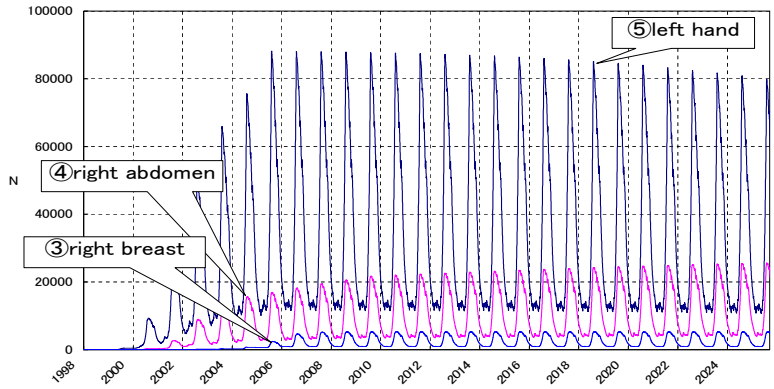


Prediction of future algae density and effect of conservation measures

- If a roof is constructed on the temple, how algae density change followed by microclimate changes?
- The precipitation and the solar radiation are changed after 10 years from the present values in calculations.

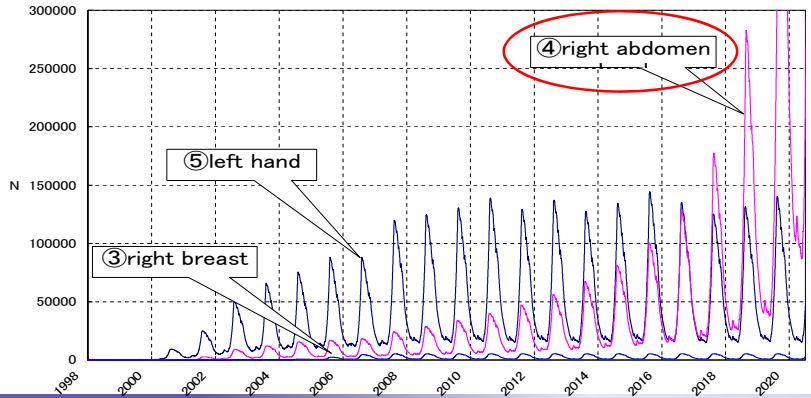
Results in case of the present condition (no roof)

- The population density of algae reaches a cyclic steady state in the year of 2008.



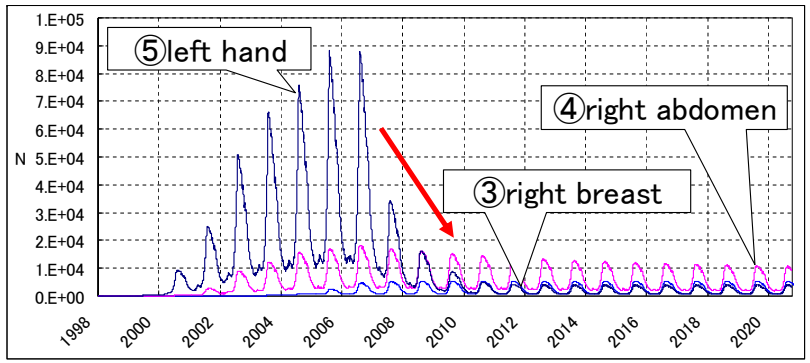
In case of a half solar radiation

- The population density increases in particular at the area ④.
- This is because the evaporation rate is decreased due to a reduction of solar radiation.



In case of no precipitation

- The density gradually decreases, and reaches a cyclic steady state.
- The algae do not necessarily disappear
- This is caused by a water supply due to condensation



Conclusions

- In this study, the relationship between the algae growth on the plaster surface and the environmental conditions was clarified, concerning the Great Buddha in Wat Sri-Chum, Sukhothai.
- Then a mathematical model predicting the algae growth which takes into account the environmental conditions was proposed. The result of the proposed model agreed well with the observed growth rate of the algae on the Buddha surface.
- This model predicts that the algae may grow more when the solar radiation is decreased, and the algae may not disappear even if the rain is completely prevented.
- The proposed method based on the prediction model seems very promising for the conservation of the historic cultural properties.

ISCS Annual meeting in Paisley, Scotland 2016

- Thank you very much

Kyoto University