Study on Mechanism of Water Condensation and Field Experiments of Thousand-Hand Guanyin in Dazu Rock Carvings

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Abstract. Dazu Rock Carvings is an important heritage. In the past, many varieties of damages existed in Dazu Rock Carvings, which impaired aesthetics and safety. Thus, the country is trying to save the rock carvings through preservation of cultural relics. Among those engaged in this endeavor are leaders and experts from Dazu Rock Carving Institute, Chinese Academy of Cultural Heritage, China University of Geosciences, School of Environment of Tsinghua University. In the research hereof, field experiments and field surveys were carried out, and corresponding measures were put forward for analysis of data.

1. Introduction
Dazu Rock Carvings in Baoding is 15km away from Dazu County, with the Buddha Bay as the center. Water condensation is very severe in the carvings of Mount Baoding, especially in the Thousand-Hand Guanyin carvings, the adjoining cottages and the Analogous Hole. The Thousand-Hand Guanyin statue is located in the Mercy House, where the air circulation is poor because of the closed building structure. On the east side, cracks and seepage springs keep the statue wet all year long, leading to severe water condensation. The condensation, in the long term, not only accelerates weathering of the Thousand-Hand Guanyin statue, but also hampers the implementation of protection technologies on the statue. It is a major issue that must be considered during the protection engineering of Thousand-Hand Guanyin. Thus, the author had two years of observation and field surveys on condensation in Mount Baoding in Dazu, and achieved the following results:

Firstly, through on-site surveys and field tests, it is found that the laminated muddy sandstone features high density, high clay content, low permeability and impermeability. Data of this area show no water seepage fissures and the Thousand-Hand Guanyin statue is not subject to the impact of groundwater seepage. Then, through a few years of observation of water condensation over the entire Big Buddha Bay, we can see that most of Buddha statues within the Bay hang flow drops in July. Based on the improved condensate collection device for the Thousand-Hand Guanyin quantitative test, it can be seen that water condensation during the day is more severe than at night. The Thousand-Hand Guanyin statue has the most active condensation in the morning, followed by the afternoon, and water condensation is weak at night.

Finally, we analyzed the rock fall on the Thousand-Hand Guanyin statue, almost every month in the destruction. Through the field condensate pH test, the Thousand-Hand Guanyin statue showed the
acidic condensate zone. Collected condensate was fresh, colorless and with a PH scale at 6, while condensate collected from the weathered rock surface was yellow and with a PH scale at 4. It can be seen that the surface of weathered sandstone has the matter of water condensation on the acidity. Condensate was collected through on-site water quality analysis experiments. Condensate collected from the small paradise was 17252.55mg / L and Thousand-Hand Guanyin was 20157.55mg / L. They are high salinity water, indicating that attachment of condensed water has dissolved a large number of minerals in the surface of Thousand-Hand Guanyin sandstone cliffs, resulting in the destruction of the structure of sandstone. Analogous Hole had the highest mineralized water seepage, the salinity of which was 20545.48mg / L, 315 times of the rain.

In the end, this paper explored condensate factors and proposed damage prevention and control measures. Dazu Rock Carvings condensate had close relationship with cave eaves, ventilation, lithology, surface weathering features and nuclear condensation. Prevention and treatment can be taken in several ways: firstly, setting a floor drain before the statue of Thousand-Hand Guanyin ground, which is convenient for water clean-up and helps reduce the air humidity of the Mercy House. Secondly, managing water seepage cracks at the east of the Buddhist Guanyin statue and reducing the water vapor source. Thirdly, making use of infrared thermal imaging for more precise delineation of the aquifer rock. It is recommended that infrared thermal imaging scan be used once a month to enhance accuracy. Figure.1 below shows the protection of the Thousand-Hand Guanyin[1].

![Figure.1 protection of Thousand-Hand Guanyin](image)

2. The formation of condensation water

Excessive humidity is the internal cause of condensate formation, and others are the external causes. The process is called condensation of water vapor from gas into liquid. In the atmosphere, as long as the vapor pressure reaches or exceeds the saturation point, water vapor condensation occurs, but in the pure air, even if the relative humidity of supersaturated water vapor is 100% ~ 300%, condensation still won’t happen and the result is mere supersaturated water vapor. This is because the pure air does not have a large amount of hygroscopic particulate matter, which is the nucleus of water vapor condensation. Therefore, the two main factors that form condensation water are the condensation nucleus and humidity.

In summer and fall, the temperature difference between the surface of the rock cave and the wall can reach more than 10 °C. The temperature below the surface of the rock in the hole is lower than the temperature outside the cave. It is easy to form a low temperature zone on the wall of the cave, so that the oversaturated water vapor layer condenses, causing condensation on the surface of the cave wall with the lowest temperature. The winter spring season has a small temperature difference, even if the humidity is high and it doesn't cause condensation [2].

The supersaturated water vapor in the air inside the cavern with higher humidity is the internal cause and necessary condition for the formation of condensate. During the summer, humidity in the
Dazu grottoes area is very high. From July to September, the humidity of the caves is above 85%, and sometimes it is even oversaturated. The seepage of the caves will increase the humidity inside the caves.

3. Condensate observation
Condensate observation is a long-term and very important assessment method for the study of condensate, including visual and instrument monitoring at the scene. The real-time monitoring of condensate by the temperature and humidity meter can determine the time period of production, and the time of condensate (t) can be determined by the actual naked-eye observation at the site.

3.1 Observation of Thousand-Hand Guanyin condensate
(1) arrangement of condensate observation points
In order to observe the process of the disease, seven observation points were selected on the cliff wall of Qianquan Guanyin. The daily observation time was 9:00~10:00 a.m. 12:00~13:00 noon; 15:00-16:00 p.m.
(2) the level and distribution of condensate water
Different degrees of condensation have different manifestations on the wall. It can be described as follows:
A. dry
There is no condensation water on the cliff face of stone carvings, and the rock wall is dry and yellow.
B. wet
The cliffs are beginning to produce condensation. Because the sandstone cliff wall surface generally presents loose sand weathering, the newly formed condensation water is adsorbed on the loose surface, resulting in wet and dark-colored cliff walls. The condensation is minor [3].
C. occurrence of water droplets
The condensation water is formed on the surface of the cliff wall, and the phenomenon of condensation water is of great severity (Figure 2). Coagulation water damage is more serious.
D. Hanging current
Due to the increase of water droplets, the diameter increases, and finally, under the effect of gravity, it flows downward, forming a suspended flow, and the condensate is severe (Figure 3). The condensate damage is serious.

![Figure 2: Occurrence of water droplets](image-url)
E. Accumulation of water
The condensate flows along the cliff surface down to the ground and forms water; the condensate is extremely serious, leading to severe damage.

The distribution of the condensate in the Guanyin area is as follows:
Water condensation of the Thousand-Hand Guanyin carvings has a tendency to decrease from the bottom up. Areas around the Lord presents the most severe condensation; the severity level of condensation decreases from east to west on the upper part of the carvings, while from west to east on the lower part. The reason may be that the Great Sorrow Pavilion is more closed, the lower east side is close to the water source, and the upper eastern area is near to the air inlet.

3.2 Data analysis of condensate water monitoring in the Thousand-Hand Guanyin construction area
It can be inferred from above that condensation distributes unevenly around the Guanyin carvings area. To facilitate comparative analysis, China University of Geosciences installed dew point temperature and wall temperature monitoring devices at four corners, namely the most representative monitoring points, of the Guanyin carvings[4].

Layout of monitoring devices is shown in figure 4. WP1 and WP3 is on the western side of Guanyin, while WP2 and WP4 on the western side. Each monitoring device consists of a microenvironment temperature and humidity probe and a rock wall probe. The temperature and humidity probe is fixed in the atmospheric environment of the monitoring point, and the rock wall temperature probe is fixed on the rock seam or the surface of the rock wall. Water condensation at the four monitoring points in the Thousand-Hand Guanyin construction area was very severe in the three months of May, June and July, and the time of condensing water at each point accounted for more than 70% of the total monthly or statistical time. According to field observation data obtained in May, June and July, water condensation is serious, especially in the first halves of June and July when condensation occurs almost all over the niche. Most of the time, the condensate is in the form of water.
droplets or hang flow, and when the condensation of water intensifies, it forms a large number of water flow to the ground.

4. Quantitative determination of condensation water

For quantitative evaluation of the condensate, the major challenge and key point is the quantitative description of the microscopic condensation process. The invention of condensate collector solves this problem. The coagulation rate of condensate on the cliff wall can be measured accurately by using the condensate quantitative acquisition instrument modified by China University of Geosciences (Wuhan).

At present, there is no suitable measuring device at home and abroad to accurately determine the amount of condensation on the rock surface, so it is not feasible to carry out quantitative research on the condensation water of grottoes. For this reason, China University of Geosciences (Beijing) has developed a quantitative measuring device for condensate water, using the principle of airflow circulation drying, to accurately determine the amount of condensation on the rock surface.

![Beijing condensate test instrument](image1)

![Wuhan condensate test instrument](image2)

In 2009, the quantitative determination of condensate (Figure. 5,6) was carried out by the condensate quantitative tester developed by China University of Geosciences (Beijing). In 2010, China University of Geosciences (Wuhan) used a new condensate quantitative test instrument to carry out quantitative determination of condensate water of the Thousand-Hand Guanyin carvings.

5. Factors that affect the damage of water condensation

(1) the effect of the roof and ventilation on water condensation

The formation of condensed water is closely related to the internal air circulation. Even when the humidity is less than 70% and the temperature difference is small, there is still the presence of condensation in the depths of the cliffs. This indicates that the flow rate of air in the pavilion is low, which retards the process of evaporation. Evaporation and condensation are reciprocal processes, and the control factors of this process depend mainly on the dynamic equilibrium system of external conditions. On the contrary, when there is no wind and the roof of the cave is covered, the evaporation process is weak and the coagulation effect is enhanced, resulting in a large amount of condensed water attached to the sculpture.

To break the dynamic balance and improve the ventilation condition of the caves, the environment of the cave can be controlled and developed in the direction that is conducive to the protection of sculpture.
(2) Influence of lithology and weathering crust surface characteristics on water condensation
The Thousand-Hand Guanyin is composed of a kind of sandstone with high muddy quality, and the surface of sandstone has suffered a certain degree of weathering, which forms the surface of weathering. A fresh sandstone surface is prone to generate condensed water droplets.

(3) Effect of condensation nuclei
The preliminary findings of the investigation showed that the rough areas of the wall had more dust particles and became the places where the water vapor condensed. It can be observed that a large number of condensation water beads with dust grains are suspended above the cliff wall. The particulate matter contained in the atmosphere of the cave will absorb water vapor, which will coagulate and form water droplets at the right temperature, and will be attached to the wall surface.

(4) the influence of water seepage
On the eastern side of the Guanyin carvings, there are seepage water cracks and traces of staggered development. When it rains, rain runs along the horizontal plane fissure to the grottoes. Typically, the rain penetrates the cracks around the Buddha feet along the horizontal direction into the area of Guanyin carvings, resulting in long time of high moisture on the eastern side of the Guanyin carvings. Long time of high moisture and severe humidity in the recess further aggravate the formation of condensed water. This is also the main reason why the eastern part shows most severe water condensation.

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