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3.3 Control of Coarse Particle Intrusion into Museums and Archaeological Sites

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Period of Activity: 7/90 to present

Project Abstract

This project has three major study objectives:

1. To study the depositional characteristics of course particles on vertical surfaces. This involves the subtasks of perfecting a measurement procedure and improving existing theories, which in their current state inadequately explain why deposition occurs.

2. The theoretical treatment of fluid dynamics of caves and "blind holes," flow in and out of pores, air movement over small-scale surface texture, and pressure differentials in cracks and porelike structures.

3. Study of passive filtration systems (for application in caves, architectural enclosures, and other display environments); what does a slow speed variable airflow mean in terms of filter porosity, and can passive particle filtration be made to work?

While the above work applies to historical house environments, the field site actually used was the Yungang Grottoes near Datong, China. The final report is due in Winter 1994. These include intense diurnal variation and longer seasonal deposition studies.

Primary Publications

Christoforou, C. S., L. G. Salmon, T. J. Gerk, and G. R. Cass, "Approaches to Control of Particle Deposition and Soiling within the Yungang Grottoes,"

Paper presented at the Dunhuang Conference, China, October 3-8, 1993. To be published by the Getty Conservation Institute in Summer 1995.

ABSTRACT-The Buddhist grottoes at Yungang are soiled at a rapid rate by deposition of airborne particles. These particles enter the caves from outdoor where contributing sources can be identified as coal-mining activities, coal combustion, fugitive road dust, fugitive soil dust, and regional dust storms. During 1991-1992, a series of experiments were conducted to assess the contribution of nearby sources to the high particle concentrations at Yungang

Methods for reducing the soiling rate within the caves fall into two categorie (1) those designed to reduce particle concentrations in the outdoor atmospher and (2) those designed to prevent outdoor particles from entering the caves. The likely effect of several simple methods for reducing outdoor particle concentrations is quantified here, including diversion of the coal truck traffic away from the caves or alternatively covering their loads, paving the dirt roads in the village of Yungang, spray-washing local highways as a means of dust suppression, and controlling dust generated in the area immediately in front of the caves.

A computer-based model that simulates air flow into the caves and particle deposition within the caves can be used to compute the effects of particle filtration systems and/or altered ventilation rates on soiling within the grottoes. Calculations show that a mechanical air filtration system can be bui that can reduce particle deposition rates by 66% to 95.5%, depending on the quality of the design and the filters chosen. An approach employing improve outdoor site management practices combined with installation of particle filtration systems would effectively reduce soiling rates within the Yungang Grottoes.

Salmon, L. G., C. Christoforou, and G. R. Cass, "Airborne Pollutants in the Buddhist Cave Temples at the Yungang Grottoes, China," Environmental Science and Technology, 1994, in press.

ABSTRACT-The Buddhist cave temples at the Yungang Grottoes, China, experience rapid soiling due to the deposition of airborne particles. Contributing sources include coal mining and combustion, fugitive road dust, and regional dust storms. Both particle and gas-phase air pollutants are characterized at that site. Annual average coarse (diameter, dp > 2.1 mm) particle concentrations outdoors average 378 mg/m3, increasing to more than 1200 mg/m3 during peak 24-hour periods. These coarse airborne particles include crustal dust (e.g., soil dust; over 80% of coarse mass) and carbon-containing particles (10%). Fine airborne particle concentrations (dp 2.1 mm) outdoors average 130 mg/m3 and consist mainly of carbon-containing particles (45.5%) and crustal dust (24%). Airborne particl concentrations inside Cave 6 average approximately 60% of those outdoors. SO_2 is the principal gas-phase air pollutant averaging 31 ppb outdoors and 1 ppb inside Cave 6 over the year studied. Other pollutant gases are present at lower average concentrations: NH_3 (4-10 ppb), NO_2 (4-6 ppb), HNO_3 (0.1-0.2 ppb) and HCi (< 0.1 ppb).

Christoforou, C. S., L. G. Salmon, and G. R. Cass, "Deposition of Atmospheric Particles within the Buddhist Cave Temples at Yungang, China," Environmental Science and Technology, 1994, in press.

ABSTRACT-The Buddhist Cave Temples at Yungang, China, are soiled at a rapid rate by the deposition of airborne particles. Average mass deposition rates to horizontal surfaces of 13.42 mg m-2 s-1 outdoors and 5.23 mg m-2 s-1 inside Cave 6 were measured over a one year period in 1991-92. These rates are comparable to the rates inferred by examination of historically accumulated deposits within the caves. The surface area coverage by coarse particles is dominated by particles larger than about 10-20 μm in diameter. Comparison of the deposition rate in Cave 6, which retains its wooden templ front structure, to that in Cave 9, which is open to the outdoors, shows that th temple front does provide some protection. During spring 1991, the deposition rate to horizontal surfaces in Cave 6 was 4.5 μm m-2 s-1 compare to 13.4 μm m-2 s-1 in Cave 9 and 21.5 μm m-2 s-1 outdoors.

Chistoforou, C.S., L.G. Salmon, and G. R. Cass, "Control of Airborne Particl Deposition Within the Buddhist Cave Temples at Yungang, China," Final report submitted to the Getty Conservation Institute, California Institute of Technology, June, 1995, 170 pages.

ABSTRACT- The Buddhist cave temples at Yungang are carved into the sid of a cliff in the Wuzhou hills overlooking a river valley, and are adjacent to the small village of Yungang. The site is located approximately 16 km west c the industrial city of Datong near the Inner Mongolian border in northern Shanxi Province, China. Excavation of these cave temples began in 454 A.D. under the patronage of the emperor of the Northern Wei Dynasty, Wen-ch'eng. Over a period of approximately a half century, twenty major caverns and numerous smaller caves were carved out of the sandstone cliff.

The largest grottoes are similar in architecture. A passageway dug into the cliff face at ground level opens into a large man-made cavern excavated behind the cliff face. These rooms within the cliff are typically rectangular, between 10 to 15 meters long on each side and approximately 12.5 meters high. At the rear of some caverns, and at the center of others there is a huge pillar that stretches from the cave floor nearly to the ceiling. This central column typically is carved into a monumental statue of the Buddha, but there are examples of pillars that take the form of a pagoda. The walls and ceilings of these caves are covered by thousands of carved, and in some cases painted sculptures that include objects of reverence to the Buddhist faithful and tell stories of the life of the Buddha. In antiquity, the entrances to each large cave were covered by a wooden shelter several stories high by one room deep. In 1991, only Caves 5 and 9 retained the wooden structures in front of their entrances. The remaining caves in 1991 existed with entrances open to the outdoor air allowing abrasive windblown dust and air pollution present in on(of China's largest coal mining districts to enter the caves and subsequently deposit onto the sculpture without restriction. The deposits of dust obscure features of the statues and degrade the painted surfaces.

The sources of airborne particles are many and include dust and smoke produced by operations at the coal mines and dust generated by coal trucks oı a highway that runs within a few hundred meters of the grottoes. Coal combustion occurs from home cooking and heating in the village, and coal-fired locomotives run on nearby railroad tracks. Fugitive soil dusts is generated by traffic on unpaved roads and sidewalks in the village of Yungang and by visitors to the caves. In addition, the caves are not far from the Gobi desert, and desert dust storms can affect the site.

The purpose of this research effort is to establish new methods for the measurement, characterization and control of coarse airborne particle deposition within cave temple sites like the Yungang Grottoes. In brief, our approach will be to first demonstrate methods for measurement of the concentration, range of particle sizes, and chemical composition of the coarsε atmospheric particles found in the polluted outdoor air. Fast, efficient methods to measure and monitor particle deposition rates onto surfaces also will be developed. Fluid mechanical models will be built that can predict the rate at which polluted outdoor air will be drawn into structures by means of natural convection flows. Particle deposition from these natural convection flows onto interior surfaces will be tracked. The methods will be evaluated fc the control of such particle deposition and soiling problems. Control methods studied include reduction in particle generation at local pollution sources, removal of particles from the air entering the interior spaces via mechanical air filtration systems, and the development of "passive filtration" systems in which air motion through the filters in induced by a natural convection flow without the use of mechanical fans. Methods developed will be tested against experimental observations of the particle deposition problem that presently exists at the Yungang Grottoes in China.

In Chapter 2, the results of an extensive one-year monitoring experiment conducted during 1991-1992 at the Yungang Grottoes, Datong, China are presented. Data are obtained on airborne particle concentrations and chemica composition outside the caves and inside two of the caves: Cave 6 which retains a wooden temple structure sheltering its entrance and Cave 9 that is open directly to the outdoor atmosphere. Measurements also are reported of the concentration of certain gaseous pollutants that could effect the stone or painted surfaces within the caves including SO2, NO2, HNO3, HCl, and NH3. This experimental program provides baseline data on air quality both inside and immediately outside of the Yungang Grottoes that define dust and smoke concentrations present in the outdoor air and the fraction of the material that is found inside the caves.

Work in Chapter 3 focuses on determining the size distribution of both airborne and deposited particles at Yungang. This information is crucial to engineering calculations needed for control system design. Particle depositioı fluxes to both vertical and horizontal surfaces within the caves are also measured. This allows deposition rates measured during the 1991 experiment to be compared to historically observed deposition rates and quantifies the actual problem that needs to be controlled.

The fluid mechanics of air exchange that brings airborne particles into the cave temples at Yungang is explored in Chapter 4. Measurements of the air exchange that transports outdoor airborne particles into the caves are reportec along with the cave wall/air temperature differences that cause this air exchange. The purpose of this work is both to document the rate of air exchange through the Yungang Buddhist Cave Temples, and to develop the capability to predict air flows under the influence of changing environmental conditions such that, in the future, estimates can be made of the changes in ai exchange that will occur if the existing shelters in front of the cave entrances are modified slightly or if new shelters are erected in front of those caves thai presently are open directly to the outdoor atmosphere.

In Chapter 5, a mathematical model is developed that combines air exchange calculations with particle deposition calculations in order to predict particle deposition rates within the caves given only data on outdoor pollutant concentrations, outdoor air temperatures and cave wall temperatures. This model combines all data and makes it possible to predict the particle deposition rates that will occur if new or modified shelters are erected in fron of the caves or if control systems are devised to filter particles from the air entering the caves.

The character and origin of the dust deposition problem at Yungang is examined in Chapter 6. The chemical character of local sources of particles released to the atmosphere is studied as a possible means to identifying the presence of material from specific sources within the deposits in the caves. A study is conducted of community-wide particle deposition patterns at more than 20 sites within a 2 by 2 kilometer area centered on the grottoes, with particular emphasis on the role of coal truck traffic on nearby roads as a source of fugitive dust. By mapping the spatial distribution of the particle flu: in the countryside surrounding the grottoes, areas of the highest deposition flux can be found that indicates close proximity to a major particle source, thus identifying the source itself.

The overall purpose of this work is to characterize the exposure of the grottoes to air pollutants in a manner that will establish a basis for the future protection of the grottoes from air pollution damage. Chapter 7 explores strategies that can be used to reduce the particle deposition within the caves including reduction in particle emissions at the outdoor sources, alteration of air exchange rates through the caves, and use of filtration systems to remove particles from the air entering the caves.