Conservation and Restoration

CHURCHES, SYMBOLS OF COMMUNITY: THE PRESERVATION OF NEW MEXICO'S ADOBE CHURCHES

Nancy Arnon and Sam Baca
New Mexico Community Foundation
110 North Guadalupe Street, Suite 6
Santa Fe, New Mexico 87504
U.S.A.

ABSTRACT

The preservation of historic adobe churches in New Mexico results from a dynamic community process using appropriate technology. The preservation process relies on the traditional community-oriented, hands-on, low-technology approach. Sense of community is paramount to the preservation of the church through established traditions of cyclic maintenance. Yet, economic depression and declining populations are contributing to the breakdown of this necessary element in the preservation process.

In 1985, the New Mexico Community Foundation (NMCF) initiated the "Churches: Symbols of Community" project to assist communities in the continued preservation of their historic churches. NMCF assists in the revitalization of the social patterns and technological traditions that originally produced and cared for these buildings.

Through the partnership of national, state, and local organizations, communities are restoring their churches to a maintainable level using a tradition of cyclic maintenance.

KEYWORDS

Preservation, Adobe Churches, Cyclic Maintenance, Cultural Tradition, Available Technology, Community Involvement

Figure 1
Map of the Interior Province of New Mexico 1779.

Introduction

New Mexico occupies a unique niche in the architectural history of the United States. The long-standing traditional use of earth as a building material began well before the Spanish occupation in the sixteenth century and continues as a major architectural element today. Of particular note are the historic adobe churches. These archetypal churches are the symbols of community life. Often, in isolated villages, they are the first and only public structure built and cared for by the community. They illustrate past and present community organization, resources, self-sufficiency, and pride.

The "Churches: Symbols of Community" project was conceived as a means to assist communities in preserving these significant religious edifices. Physical preservation of adobe structures requires long-term commitment involving community dedication and participation, decision making and implementation. Working through existing local community structure, the New Mexico Community Foundation assists communities with technical advice, fund raising, research, and training, while also facilitating the necessary communication between those involved. If requested, the NMCF also helps cosponsor workdays where outside community volunteers work together with the local community in the preservation of the church. All decisions are made by the community. This preservation approach has resulted in a comprehensive survey and evaluation of historic churches in New Mexico, identification and interaction with community members, response to requests for technical assistance and the development of preservation plans now in various stages of implementation by the communities.

Background of Cultural Traditions

The earliest churches in New Mexico were constructed under the direction of Franciscan friars in the seventeenth and eighteenth centuries when New Mexico was a remote province of New Spain. The churches and surrounding communities were clustered near Indian Pueblos along the Rio Grande (see fig. 1). The adobe church was located in a prominent location along the plaza (see fig. 2).

The churches focused community effort utilizing all available local materials and human resources. The adobe walls were constructed by the women and children while the men felled the trees and shaped them into roof beams. The women plastered the walls with mud mixed by the men.

Recognizing the necessity for cyclic maintenance, "in 1731, Father Juan Miguel Menchero admonished the friars to emulate the zeal of the 'old Fathers' in maintaining the fabric of their churches and coventos, especially in repairing drains and other things that can cause their destruction" (1). Cyclic maintenance activities, similar to those required today, included remudding the walls and floors, cleaning out the wooden canales, or roof drains, and removing bird's nests. The flat mud roofs retained water, and periodic maintenance consisted of replacing rotted roof timbers and the upper courses of adobe bricks.

During the latter part of the eighteenth century, settlements spread outwards into the adjacent mountains and valleys as the Rio Grande Valley became crowded, and irrigable land grew scarce (see fig. 3). Despite the decreasing number of Franciscans, church building continued led by determined community members. "By the early nineteenth century, the Church in New Mexico had become for a majority of New Mexicans a Church without clergy" (2). To fill this vacuum, men united in a religious society known as the Brothers of Our Father Jesus of Nazareth, or commonly called Penitentes. The Hermanos, or brothers, "periodically sacralized an entire settlement". The morada, or chapel, became the center from which processions to calvarious, composantos, oratorios and churches wove a kind of sacred network around the community" (3).

The nineteenth century introduced an era of rapid regional socioeconomic changes brought about by the naming of New Mexico as

Figure 2
Aerial View of Typical
New Mexico Village

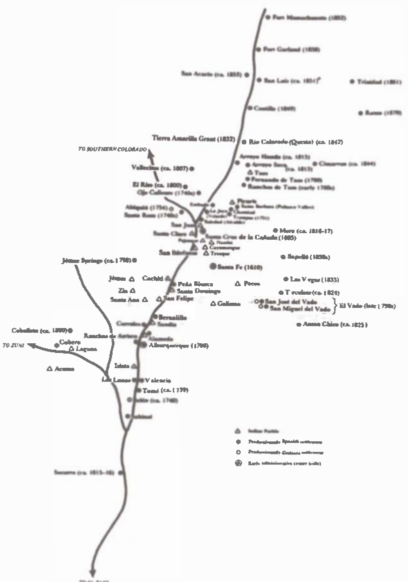


Figure 3
Schematic Diagram New Mexico
Hispanic Settlements
Drawing by M. Weigle

Figure 4
San Jose de Gracia Church
Las Trampas, New Mexico
Photo by Kirk Gittings

a United States Territory. In the latter part of the century, the railroad linked New Mexico to a larger network of available resources. New factory-produced materials such as concrete and glass became available. Viewed as technologically superior and labor-saving, new materials began to replace traditional materials. Labor-intensive mud plaster was often replaced by cement stucco. Only in the more remote villages did the use of traditional materials continue (see fig. 4).

The railroad brought not only new material but an influx of "outsiders". The solidarity of the Hermanos was cemented to counteract the influences of foreign cultures. Consequently, they became a major political as well as social force. "By preserving long-standing Hispanic Catholic traditions, the Brothers of Our Father Jesus contributed substantially to spiritual security and physical survival in isolated village" (4).

Maintenance of the churches was supervised in the past, as it is today, by mayordomos, or lay church caretakers. Each year, new mayordomos were selected during the funcion or celebration of the feast of the patron of the church and community. Following the Second World War, the populations of rural villages began to dwindle triggered by faltering local economies. The tradition of cyclic maintenance of the church rested on decreasing populations consisting largely of older parishioners. Despite adverse conditions, church maintenance continued under the guidance of the mayordomos and Hermanos. When a church was not being maintained, the Hermanos often moved sacred artifacts into the moradas for protection from vandilism and moisture.

During the early twentieth century many new structures were constructed emulating the mission style of architecture, which rekindled an appreciation for the original mission churches. The increased awareness of the churches and their deteriorated condition led to isolated restoration projects. In 1985, the first survey of historic churches was initiated by the State of New Mexico Historic Preservation Office and the New Mexico Community Foundation with funds from the National Historic Preservation fund and the National Endowment for the Arts.

Archbishop Robert Sanchez formed the Commission for the Preservation of Historic New Mexico Churches in 1987. The Commission was conceived to set policies for and oversee the preservation of historic Roman Catholic churches in the Archdiocese of Santa Fe. The southern Diocese of Las Cruces and western Diocese of Gallup also work for the preservation of their churches as do Protestant church owners.

Today, through the creation of a partnership among communities, church leaders, the New Mexico Community Foundation, many volunteers and funding sources, the historic adobe churches are being preserved for future generations to enjoy.

Preservation Approach

New Mexico Community Foundation works with communities using a preservation process which reinforces the historic fabric by encouraging the values, traditions and techniques which created and still support the churches. The process simultaneously diminishes major threats of deterioration while strengthening a community's ability to continue preserving its church (see fig. 5).

Preservation of established churches is characterized by communal cylic maintenance where the mayordomos and/or Hermanos lead annual work on the church. This tradition has resulted in the presence of over 800 adobe churches in the State today.

Respecting the patterns of community preservation, the "Churches: Symbols of Community" project follows the basic principles:

1. community decision making
2. community input and information exchange at each step
3. honor and respect for communities and churches
4. respecting the pride of ownership

NMCF encourages communities to use sound conservation principles. Communities are recognizing that the best available means of preserving adobe structures is through the use of traditional methods and materials. The potentially deleterious effects of incorporating modern materials is evident in the many examples of deteriorated adobe churches clad in cement stucco. For instance, the community of Ranchos de Taos decided to remove

Figure 5
Work in Progress
La Capilla de San Antonio
Chacon, New Mexico

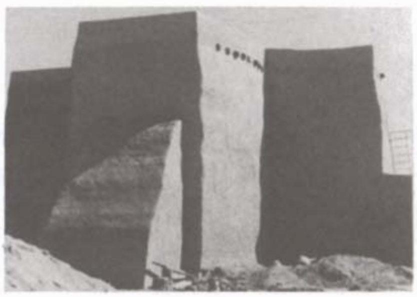


Figure 6
Rear Facade
San Francisco de Assisi
Ranchos de Taos, New Mexico

Figure 7
Community Discussion of Work
Chacon, New Mexico

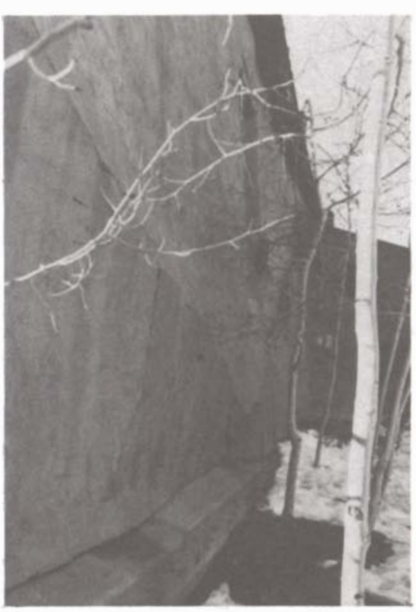


Figure 8
Distressed Cement Stucco
Holy Trinity Church
Arroyo Seco, New Mexico

the cement stucco from their church in the 1970's. The rear adobe buttress had almost completely disappeared leaving only the cement stucco skin (see fig. 6). Each year community members donate a week each of their time to replaster the church using mud.

The development of preservation plans and implementation must be accomplished through sensitive explanation of successes and failures (see fig. 7). Modern technological advances employed in past maintenance projects were considered state of the art and were utilized as the best available means to maintain the church. The Taos community's observation of increased and rapid deterioration of the adobe structure as a result of the use of inappropriate advanced technology has led to reconsideration of the use of traditional materials and techniques.

An awareness of community concerns is crucial, regardless of amount of time consumed, to maintain a relationship of mutual respect. Often, traditional materials are thought to be inferior. In rural communities, adobe is often associated with economic depression. In Chacon, the building committee of La Capilla de San Antonio was divided over tearing off the cement stucco and concrete plynth or contrapared, which lined the base of the wall. Historical architect Anthony Crosby carefully pointed out the affect of cement plaster in the preservation plan:

> Damage even when it does occur is not easily detectable and a great deal of damage can occur before there is even the slightest hint that a problem exists. Hard cement stuccos do not echo internal condition until it may be too late for normal repair. In the case of Chacon, we may well have identified the problem before it becomes unmanageble. But even here some structural repair and rebuilding is necessary. As in many similar cases, water has gained access to lower portions of the walls and because of the relatively impervious stucco, has not evaporated. As the walls become wet they quickly loose their strength and initially begin to slump or compress because of the weight of the upper part of the walls (see fig. 8). As they continue to slump, structural cracks will begin to form and the entire adobe structural system may fail as portions of the walls begin to act independently (5).

Following this explanation, the community decided to remove the cement stucco and concrete plynth (see fig. 9). The harmful effect of cement on adobe structures became clearly evident upon removal of the concrete and stucco on the work day held during the summer of 1989. The walls were extremely wet. Coursing patterns of adobe bricks were indistinguishable at the base of the walls. In other places, the adobes were severely eroded. A pattern of white spots, or efflorescence, indicated that moisture had moved through the wall.

Thus, education is a major component of a community's ability to continue preserving its church. Understanding of traditional building systems, of presently available technology and appropriate use of the tecnology is a necessary ingredient in past, present, and future decision making about maintenance of the church. Preservation workdays are the best opportunity for the exchange of ideas and the education of all participants regarding the deterioration of adobe, as well as use of traditional materials and techniques. A work day sponsored by the community of Chacon involved replastering the church with lime plaster. Area professional plasters, interested in the use of lime plaster, helped replaster the church (see fig. 10) while community youth were instructed in mixing and application procedures. The result has been a renewed interest in the use of lime plaster. Similarly, during workdays sponsored by the community of Las Trampas in 1987, participants learned traditional plastering techniques from enjarradoras, or women plasterers, using mud supplied by the men (see fig. 11).

Another component of "Churches: Symbols of Community" projects is the reliance on volunteers and donated materials. A long list of technical advisors has been developed to assist communities. The networking of interested parties enlarges the resources available to a community and facilitates project implementation. Recently, an adobe yard in the southern part of the state donated adobes for the repair of the wall of a church in the northern part of the state. Volunteers rented trucks to transport the adobes to the community.

Figure 9
Cement Stucco Removal
La Capilla de San Antonio
Chacon, New Mexico

Figure 10
Lime Plaster Workday
La Capilla de San Antonio
Chacon, New Mexico

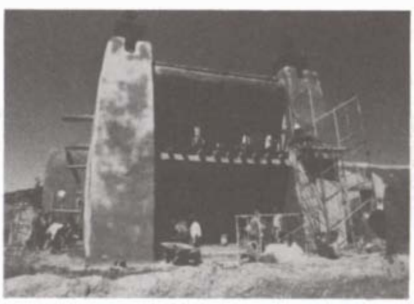
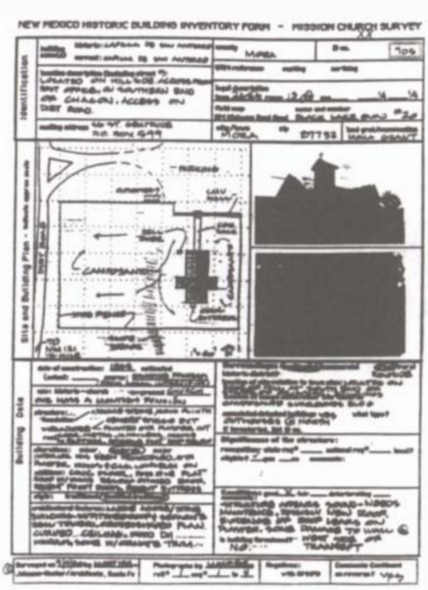


Figure 11
Mud Plaster Workday
San Jose de Gracia
Las Trampas, New Mexico
Photo by Anita Rodgriguez



NEW MEXICO HISTORIC BUILDING INVENTORY FORM - MISSION CHURCH SURVEY

Figure 12
Sample of New Mexico
Historic Building
Inventory Form
Survey of Churches

Preservation Process

The preservation process continues to evolve as each project and community make valuable constributions. Thus far, the process is the following:

1. Research
A comprehensive statewide professional survey and inventory of churches is seventy-five percent complete. The survey forms identify basic information on construction date, architectural style, architectural description, condition, photographs, sketch site plan and floor plan, and community contacts (see fig. 12).

2. Targeting
Using information from the survey, NMCF targets communities in which historic churches are immediately threatened and where community interest is high. Now that the program is better known, numerous requests for assistance are received.

3. Community Organization
Church leaders, mayordomos, and parish officials are contacted and a community meeting is held to provide information on availability of NMCF assistance, offer informational videos and handbooks if requested, assess existing resources, and help forge a plan of action (see fig. 13).

4. Community Selection
Communities are selected for NMCF assistance depending on their initiative and desire for such assistance, the extent which the church is threatened, and the availability of matching community resources.

5. Professional Site Inspection
An initial site inspection is scheduled to provide additional documentation, condition assessment, and to make recommendations for additional professional services. In some cases, all that is required is initial on-site advice. Where more serious problems are identified, a subsequent detailed site inspection may be recommended.

6. Detailed Site Inspection
A professional from a list of interested technical experts is suggested to the community to author a detailed preservation plan. The community selects a professional. The professional documents the church with photographs and drawings, collects samples, and develops a scope of work. The community reviews the plan and decides on appropriate work.

7. Implementation
A follow-up community meeting is held to set a timetable for gathering materials and labor. Local resources are used as much as possible. Once the schedule of work, crew, individuals, and costs is determined, workdays are scheduled. Outside volunteers are recruited as desired by the community. Volunteers from nearby communities or former residents are preferred. Workdays further strengthen social fabric. The mayordomo or other community-selected leader directs the workday. Additional documentation of historic materials is performed. Additional samples are collected.

8. Summary Report
NMCF writes a summary report of work accomplished, objectives attained and lessons learned during the project.

9. Training
Training programs include handbooks, videotapes, workshops and workdays. Training may be coordinated with church leaders. All phases of the process involve an exchange of techniques and skills.

Figure 13
Community Meeting to
Discuss Work

10. Networking
Key to the program is providing communities with services and materials necessary for the continued preservation of the churches. Success is measured by the gradual development of a self-sufficient network eliminating the eventual need for the "Churches: Symbols of Community" preservation project or other forms of support.

Conclusion

In a time of economic decline, rural communities often need additional support in carrying out the preservation of their adobe churches. New Mexico Community Foundation initated the "Churches: Symbols of Community" project to provide necessary assistance. Yet, the traditional bonds between community and church must not be weakened by outside intervention since it is the local resources which will continue to preserve the church. Through community-selected services and resources, the churches are restored, using traditional techniques and materials, to a condition maintainable by the communities (see fig. 14). Following this, a support network assists the communities to continue the work.

Archbishop Sanchez explains:

"The very fact that we have churches that are over 250 years old, tells us that our people have always been concerned and have always loved their churches and want to preserve them. The churches have been part of their life. And because we have them today, we need to make that effort so that our children and our children's children will have an opportunity to worship in these same beautiful temples of God that have been part of our family life" (6).

Figure 14
Removing Cement Stucco
Before Mud Plaster
San Francisco de Assisi
Ranchos de Taos, New Mexico

The ancestors of New Mexico, a land of great beauty and rich history, knew the importance of cooperation, community and cyclic maintenance. The adobe churches are symbols of that knowledge. The generations that follow retain the vivid spirit of community. Working together to maintain the church is a task that each generation carries out faithfully for the sake of the next. Today, these humble adobe churches stand as symbols of that great tradition for all the world to admire (see fig. 15).

Figure 15
Nino Jesus Church
La Puebla, New Mexico
Photograph by Kirk Gittings

NOTES

1. J. L. Kessell, The Missions of New Mexico Since 1776 (Albuquerque: The University of New Mexico Press, 1980) 11.
2. Ibid., 14.
3. M. Weigle, Brothers of Light, Brothers of Blood: The Penitentes of the Southwest (Santa Fe: Ancient City Press, 1976) 190.
4. Ibid., 179
5. A. Crosby, Preservation Plan for La Capilla de San Antonio, (Report prepared for New Mexico Community Foundation, Santa Fe, 1988).
6. "Churches: Symbols of Community" (Videotape produced by New Mexico Community Foundation, 1988).

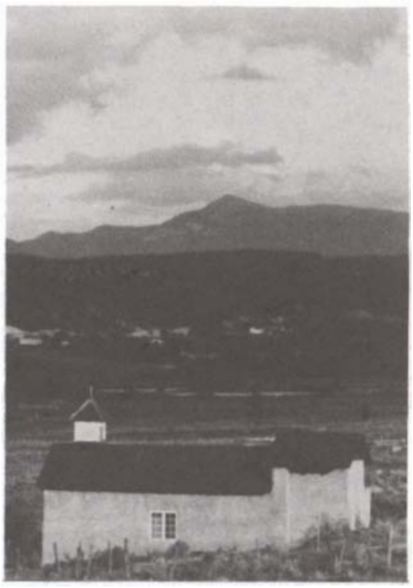


Figure 16
Adobe Church
Ojo Sarco, New Mexico
Photo by Betsy Swanson

FOOTNOTES

The New Mexico Community Foundation's "Churches: Symbols of Community" project could not exist without the generosity and support of the following:

The Graham Foundation
William and Mattie Harris Foundation
Edward W. Hazen Foundation
Samuel H. Kress Foundation
National Endowment for the Arts
National Trust for Historic Preservation
L.J. and Mary C. Skaggs Foundation
State of New Mexico, Office of Cultural Affairs, Historic Preservation Division
The Eugene V. and Clare E. Thaw Charitable Trust
World Monuments Fund
The Xerox Corporation

Technical advisors who contributed to this paper are:

Louis Castillo
Eddie Cherry
Ed Crocker
Anthony Crosby
Linda Gegick
Paul McHenry
Mark Mortier
Robyn Powell
James See
Dale Zinn
Barbara Zook

A NEW RESTORATION MATERIAL FOR ADOBE STRUCTURES

Dr. Bülent Baradan
Dokuz Eylül University
Civil Engineering Department
Mühendislik-Mimarlık Fakültesi
Bornova 35100 İZMİR-TURKEY

ABSTRACT

Turkey, an important civilization center throughout the ages, has a significant number of historical monuments and sites. Preservation of this historical heritage is an issue of prime importance. The basic building fabric in most of these historical and cultural structures and sites is earth. These buildings are more severely affected by nature throughout the ages due to well-known disadvantages of adobe such as low mechanical properties and low resistance to moisture.

A research study was performed to evaluate pozzolanic mixtures that incorporate brick powder, lime, and fly ash combinations for use in conservation problems of historical structures.

The results showed that most of the mixtures produced adequate strength and durability. It seems like an ideal material for adobe plaster amendments and historical wall treatments. Best of all, the color and texture of the mixtures can easily be modified to give the original historical appearance of the structure.

KEYWORDS

Conservation, restoration, fly ash, lime, powdered brick, pozzolanic reaction, earthen architecture.

Introduction

Earth is one of the oldest building materials known to man. It has been in use for centuries and is currently being used by a large percentage of the world's population. In addition to the continued need for earth as a construction material in underdeveloped areas, the preservation of existing monumental or historic earthen buildings has recently become an issue of major importance [1].

Basic techniques used in the manufacture of sun dried earth bricks were developed many millennia ago. Specific methods vary somewhat with geographic areas and cultural traditions, but in principle, they are basically the same. These techniques involve mixing earth or soil with water and molding the mixture into various sizes and shapes, which are then sun dried for use as building blocks. Many techniques used today have changed little from early methods. Most of these methods make use of local resources, are labor intensive, and are logical and effective [2]. However, it is common knowledge that adobe buildings are not sufficiently resistant to the destructive action of nature, especially water.

Turkey has been home to numerous civilizations dating back to the Paleolithic and Neolithic ages. Excavations have brought to light the remains of many cultures such as the early Bronze Age Hatti, Hittite, Lydian, Roman, Byzantine, Seljuk Turks and Ottoman civilizations. Adobe was commonly used by all these civilizations for structures ranging from dwellings to colossal monuments. Today, The most severely damaged buildings generally are found to be made of adobe.

Conservation and restoration of these historical sites is of the utmost importance. The use of natural unstabilized adobe plaster to preserve adobe walls has produced unsatisfactory results. Mortars made with traditional binders are not harmonius with the original structure. There is always a need for suitable restoration and conservation material that will preserve the structure without altering its original appearance.

Recent research has been inspired by a historical binder used throughout the centuries in Anatolia by Seljuk Turks and Ottomans. This binder was called "Horasan" and composed of fired brick powder, lime, and water [3]. In some references ash and egg-white are also included in this composition, but there is no evidence concerning the exact ratios of these materials. In this study, powdered brick, hydrated lime, and fly ash were used to develop a binder to fulfill these needs.

Materials

One of the most widely used building materials in Turkey is fired brick. About 10% of the 800 million bricks produced in 1988 were deformed, irregular or damaged. These by-products are not utilized in any way. For the purpose of the present study these wastes were crushed and reduced to fine powder (see fig. 1). Hydrated lime, available in commercial paper sacks, was also used.

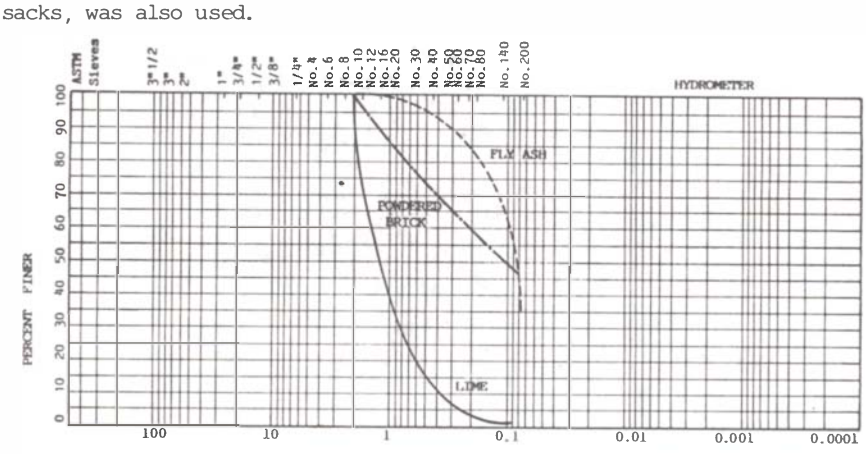


Fig. 1: Grain size distrubition of Powdered Brick, Lime and Fly ash

The other ingredient, fly ash, is a by-product of the coal combustion process at power plants. To prevent air pollution caused by thermal plants, electrostatically precipitated fly ash accumulates daily throughout the world in enormous quantities. This quantity of by product causes serious environmental, technical, and economic problems that need to be solved [4]. Fortunately, this fly ash by product can be effectively utilized because it is a pozzolana siliceous material which, in the presence of water, will combine with lime to produce a cementitous material.

In the present study fly ash samples from Soma B thermal plant were used in experiments. This plant consumes 1.75 million tons of low calorie lignite (2400 kcal/g) every year, with a 41 % C-type ash output. The chemical and physical properties of the ash are shown in Tables 1 and 2.

Table 1 : Chemical Properties of Soma B Fly Ash

Compound	Chemical Composition by weight (%)
SiO_2	47.4
Al_2O_3	25.1
Fe_2O_3	6.8
CaO	12.1
MgO	1.44
SO_3	1.60
TiO_2	0.60
Na_2O	0.10
K_2O	0.50
P_2O_5	0.30
Loss on ignition	1.1
Undet.	2.96

Table 2 : Physical Properties of Soma B Fly Ash

Property	Value
Specific gravity	2.39
Min.unit weight	1.00 g/cc
Comp.unit weight	1.18 g/cc
% Passing # 40 sieve	98
" " 100 "	96
" " 200 "	92
" " 325 "	84
Specific surface	2830 cm^2/g
Pozzolanic activity Index	82 kg/cm^2

Experimental Studies

Various amounts of fly ash and lime were added to brick powder to start pozzolanic reactions and to increase the mechanical, physical and workability properties of the compositions.

Dry and wet mixing procedures of the mortars were accomplished by means of a homogenizer and a Hobart mixer to ensure uniformity. Fabrication of the specimens was accomplished by table vibration in steel forms. The specimens were then stored under laboratory conditions until testing. Standard 4 x 4 x 16 cm prism specimens were tested for flexural and compressive strengths.

Compressive strengths were determined on portions of prisms broken in flexure test. A series of the tests were repeated on duplicate specimens soaked in water for four hours.

Compositions and their respective flexural and compressive strength variations are shown in figures 2-5.

Some of the mixtures have also been tested for their suitability as a binder material in adobe bricklaying and in plastering adobe walls.

Conclusions

From the preceeding tests and information, the following general observations and conclusions can be stated:

1. The generally required compressive strength for adobe bricks is about 1.0 N/mm^2. Even the lowest compressive strength of the test series is higher (1.2 N/mm^2) than this value. In some compositions (85% powdered brick, 12% fly ash, 3% lime) this value reaches up to 8.3 N/mm^2 in 28 days.

2. The main deficiency of adobe structures is tneir susceptibility to water damage. The mechanical properties of the duplicate specimens did not decrease meaningfully even after four hours of soaking in water. This can be attributed mainly to the pozzolanic properties of fly ash and lime.

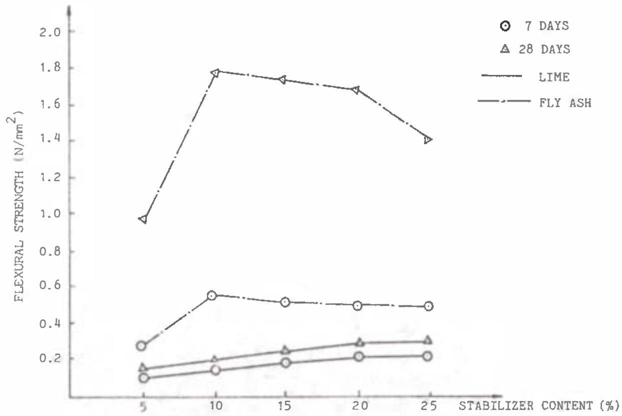


Fig. 2: Flexural strength vs. stabilizer content for lime or fly ash stabilized powdered brick.

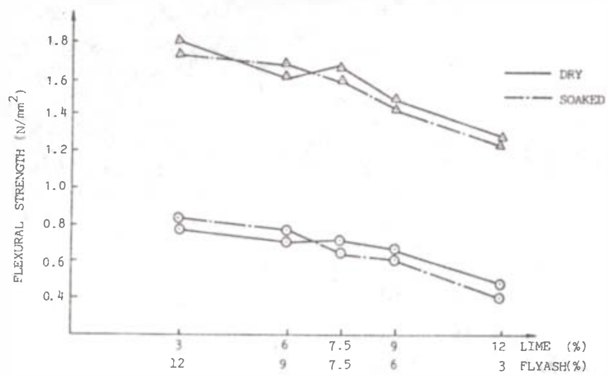


Fig. 3: Flexural strength vs. Lime/Fly ash ratio for lime-fly ash stabilized powdered brick.

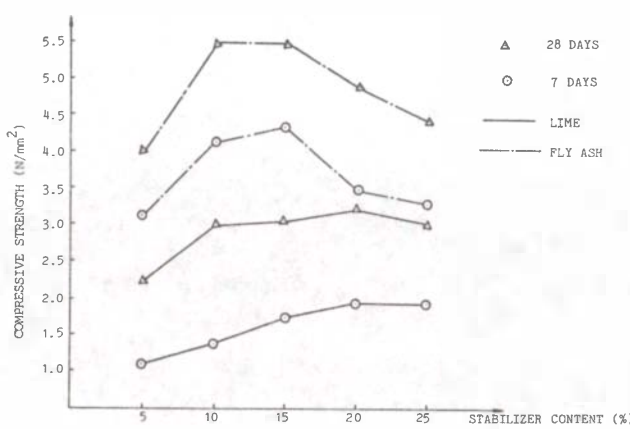


Fig. 4: Compressive strength vs. stabilizer content for lime or fly ash stabilized powdered brick.

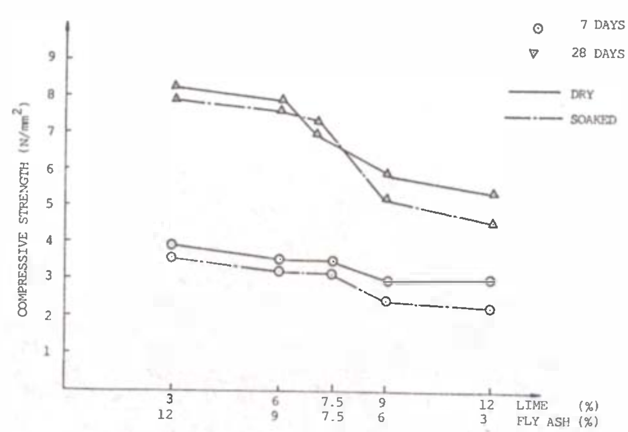


Fig. 5: Compressive strength vs. Lime/Fly ash ratio for lime-fly ash stabilized powdered brick.

3. The color of mixtures can be altered from red to grey within a wide range by changing the proportions of the ingredients. This procedure does affect the mechanical properties, but this does not create a problem due to adequate mechanical properties of all compositions.

4. These pozzolanic mixtures can be used for a variety of purposes and seem to be an ideal preservation and restoration material since they may be used in brick forming, repairing, and plastering, or as a binder.

5. The plaster application of some compositions to test walls was quite efficient and very few shrinkage cracks were observed.

6. Unit weight of specimens varied from 1.285 g/cm^3 to 1.260 g/cm^3. Coefficient of thermal conductivity λ was determined as 0.202 kcal/mh^{o}C for the mixture stated in item 1. These results indicate that these mixtures may be used in manufacturing structural elements in the form of panels or blocks. And if further tests reveal positive results, these structural elements may be economical too, since the two main ingredients, fly ash and brick powder, are discarded by-products.

References

1. T. Erdoğan, "Material Properties and Stabilization of Adobe Brick Blocks". Middle East and Mediterranean Regional Conference on Earthen and Low-Strength Masonry Buildings in Seismic Areas Conference Proceedings, Ankara, August 31 - September 6, 1986: 257-263.

2. P.G. Mc. Henry, Jr., "The Role of Earth Block Manufacturing Today" Middle East and Mediterranean Regional Conference on Earthen and Low-Strength Masonry Buildings in Seismic Areas Conference Proceedings, Ankara, August 31-September 6, 1986: 167-170.

3. M. Larousse Encyclopedia, Vol. 5, İstanbul, (1985): 605-606.

4. B. Baradan, "Fly Ash-Cement Based Structural Materials", The International Journal of Cement Composites and Lightweight Concrete, Vol. 9, No. 4 (1987): 225-228.

ABSTRACT

Efforts are underway to preserve traditional buildings in the Kingdom of Saudi Arabia. Much of this work is being concentrated at Dir'iyah, the original capital of the ruling Sa'ud Dynasty. A ruin since 1818, historic Dir'iyah is under the administration of the Department of Antiquities and Museums. Work at the site involves researching the history of the site, investigating and analyzing the surviving structural remains, understanding and developing traditional building crafts and techniques, developing stabilization and interpretive plans for significant buildings and the site in general, the construction of an on-site museum, and the selective reconstruction of significant buildings in the al-Turaif Quarter of the old city of Dir'iyah.

KEYWORDS

Saudi Arabia
Najd
architecture
adobe
stabilization
reconstruction
climate

1. Aerial view of Dir'iyah showing the locations of al-Turaif and other quarters of the city.

THE RECONSTRUCTION OF TRADITIONAL STRUCTURES IN THE AL-TURAIF QUARTER
Dir'iyah, Kingdom of Saudi Arabia

Michael Emrick, AIA*
The Office of Michael Emrick, AIA
P.O. Box 80601
Nashville, Tennessee 37208

Carl Meinhardt, FAIA
The Office of Carl Meinhardt, FAIA
520 Broadway
New York, New York, 10012

The site of Dir'iyah includes both palaces of the rulers and houses of the common people. The vast scale of the ruins, including those of the large palaces, represents an enormous task in the preservation and interpretation of the site. A major problem in researching and analyzing Dir'iyah's structures is the devastation they received at the hands of the Egyptian army. This, in combination with 130 years of neglect and weathering, has left many structures only as wall fragments. As a result of the rapid growth and development occurring in the Kingdom, in Riyadh, and in the new Dir'iyah suburb in particular, there are fewer and fewer comparable surviving structures on which to base research.

Historical Overview

The deserted city of Dir'iyah, impressive today in its ruins, is the foremost physical symbol of the longest ruling dynasty in the Arabian Peninsula, the dynasty of Sa'ud. This family made its beginnings there in 1446, founding Dir'iyah as a farming homestead. Through a combination of successful agriculture and local leadership it steadily increased its influence over adjoining territories. With increased political influence, Dir'iyah grew from a few family houses to respectable township size. Throughout, it maintained its political independence and, by its third centennial, Dir'iyah had become a well-established and respected town in the central Najd.

In 1745, the Saudi rulers entered a new phase of their history. First giving refuge to the fiery preacher and reformer Muhammad bin Abdul al-Wahhab, then joining his cause to promote morality and pious government, the Saudis became leaders of a reformist government which grew over the next seventy years to encompass nearly all of the Arabian Peninsula.

Dir'iyah remained the capital throughout this period of expansion. It underwent its greatest growth at this time, both in terms of buildings and population. By 1810 annual taxes were collected from as far as the Hijaz, Yemen, Oman, and the desert reaches of Iraq and Syria. While most taxes were spent on the burgeoning state's army, as much or more was distributed as welfare. Some funds were also earmarked for buildings in Dir'iyah as well as to house and maintain the ever increasing number of court retainers; Sa'ud bin 'Abdul al-'Aziz had perhaps 1700 in residence at his death in 1814.

At the peak of its expansion the Saudi state suffered a severe setback at the hands of the Egyptian army of Mohammad Ali. For Dir'iyah it was a death blow. Marching first into the Hijaz in 1811 to restore the Ottoman flag to the Holy Cities of Islam (Makkah and Medinah), Mohammad Ali then determined to destroy completely the Sa'ud dynasty that had seized them. In 1818 Dir'iyah fell into Egyptian hands after fierce fighting. The captured Saudi ruler 'Abdullah was sent off to Istanbul and death; Dir'iyah was evacuated and razed to prevent it from ever rising again.

Mohammad Ali's plan failed in one respect; the Sa'ud family he thought thoroughly subjugated rose only a few decades later to rebuild their independent state. Their capital, however, was moved to Riyadh. After abortive attempts to rebuild Dir'iyah immediately following the disaster, the city was ultimately left in ruin, deserted. Today its ruins stand as a living historical testimony of the ancestral home of the Sa'ud family and their first period of rule over the peninsula.

The Development of Dir'iyah

The Najd is a great plain of gravel, striated by sand bars, with occasional outcropping mountains. Settlements are found primarily in the eastern portion, grouped along the Jabal Tuwaiq Escarpment. Dir'iyah is located in the center of this arc, in the Wadi Hanifah.

Al-Dir'iyah is an oasis approximately 20 kilometers northwest of present day Riyadh (see fig. 1). The wadi, a narrow ribbon hemmed in by abrupt cliffs on both sides, flows southeast through the upper part of the oasis, bending east before passing through the main settlements. Date gardens are on a raised step above the valley floor, protected from the floods by a levee of large stone blocks as high as 3 meters.

* Author to whom correspondence should be addressed.

Evolving into an integrated group of hamlets and date groves within and along the wadi, Dir'iyah's fortifications were gradually extended to encompass increasingly larger areas of settlements and agricultural activities. By the late eighteenth century Dir'iyah was enclosed by a perimeter wall over 15 km in length. The evolution and construction of the al-Turaif Quarter of Dir'iyah (see figs. 2, 3) for the Sa'ud family and their retainers indicates the increase of political power and influence they, and Dir'iyah as their capital, came to exert on the Najd.

2. Plan of the al-Turaif Quarter showing the locations of the Palace of Omar (1), the Subaalat and Mosque of Moudhi (2), and the al-Turaif fortifications (3).

Najdi Society

Najdi society was the least influenced by non-Arab elements because of its remote location from the coastal areas. But this society was not completely isolated as the Najd was situated on the major trans-Arabian caravan routes connecting the Red Sea, Makkah, and Medina on the west with the Gulf and Syria on the east as well as Yemen in the south. It was, perhaps, the religious attitudes of this area during recent centuries that tended to make this area appear more remote and less open to foreign ideas.

Dir'iyah began to grow and become more cosmopolitan as it attracted supporters of Shaykh Muhammad bin Abdul Wahhab. And as it grew, Dir'iyah became a center of learning, a magnet for merchants, and a focus of people looking for work.

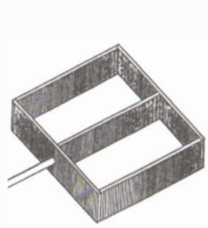
3. Aerial view of the al-Turaif Quarter of Dir'iyah taken in the 1950's.

Saudi Traditions and Techniques in the Use of Adobe

Najdi architecture may be termed "traditional" or "vernacular" in that it has been generated by a regional response to climate as well as social and political considerations. Major factors defining this design tradition in the Najd were building materials and available skills. Traditional building changed little between the time of the first Saudi state and the mid-twentieth century. The structures surviving at Dir'iyah thus provide a continuing basis for understanding this vernacular tradition.

The traditional architecture of the Najd is dominated by adobe construction. Yet the structures of Dir'iyah frequently have numerous courses of cut limestone as foundations. Geological circumstances provided the Dir'iyah area with an abundance of stone. The natural layering and fragmenting of the stone wadi cliffs allowed for relatively easy quarrying. The concentrated use of stone indicates that labor was imported from other regions where knowledge of stone construction was more advanced.

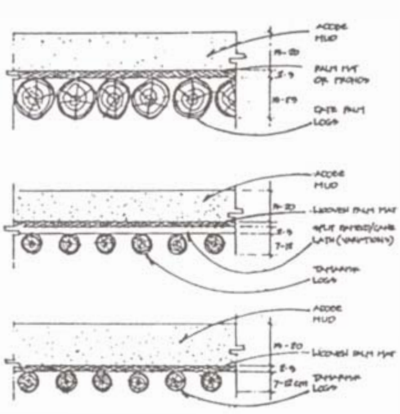
There were also specialists who made adobe bricks using rectangular wood frames (*al milben*, see fig. 4) which were set on level ground and filled with wet mud. The clays and sands of the region are particularly well-suited for making adobe bricks and plasters. Adobe was also used as a roofing material. Supported by wood logs (tamarisk and date palm) set close together, the logs were covered by a thick palm frond mat layer which was, in turn, covered by a thick layer of adobe mud to form the roof (see fig. 5). Other specialized craftsmen did the plastering and decorated doors, windows, lintels, and beams.



4. Sketch of the box frame (al Milben) used for making adobe bricks.

At al-Turaif extensive coursed stone foundations were used in combination with adobe brick walls. Walls were also constructed with various layering techniques utilizing stone fragments laid horizontally or in herring-bone fashion in adobe mud beds (see fig. 6). Except for the exposed stone foundations, walls were coated with thick layers of adobe and gypsum plasters. Long thin stones were used to frame many of the nonrectangular wall niches and openings, in particular the traditional triangular keel arch found in mosques (see fig. 7). Logs were generally inserted into the walls as lintels for rectangular doors, windows, and niche openings.

Saudi architecture relies on post-and-beam construction. Roof joists were set directly into the adobe walls, while larger beams sat on stone plates set into the walls to distribute the load and to prevent the adobe bricks from crushing. Columns were used to develop large interior spaces (see fig. 8). These consisted of rough-hewn cylindrical stone drums set in adobe mud mortar and finished with a coat of gypsum plaster. Each column had a rectangular flat stone corbel capital that supported the large multiple log wood beams.



5. Sections illustrating typical types of floor/roof construction.

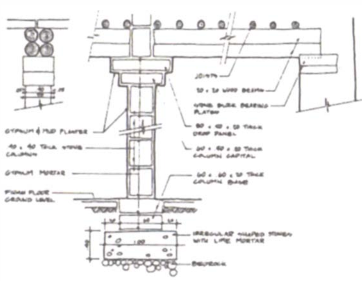
Water removal was handled by downspouts placed about the perimeter of exposed roof areas (*mirzam*, see fig. 9). These consisted of half-hollowed tamarisk logs built into the roof construction. Roofs were sloped towards these downspouts, which were notched at the outer end to provide a drip to throw water away from the walls.

Ventilation openings were of major importance in controlling the climate of the interior spaces. Dir'iyah's buildings exhibit a wide variety of patterns of small triangular and rectangular openings in the upper levels of exterior walls (see figs. 10 - 11). These openings provided ventilation and privacy as well as being decorative. During the winter months the openings were plugged with mud plaster to prevent the entry of winter cold and to help retain heat.

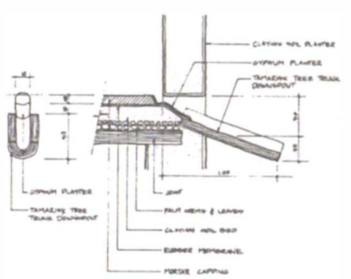
Decorative crenelations (*shurofaṭ mudarrajah*, see fig. 12) were found on parapet walls at the roof level and on courtyard railings. These provide modest decoration on the otherwise stark, massive building forms. Ornament and display

6. Example of horizontal coursed stone used in in wall construction.

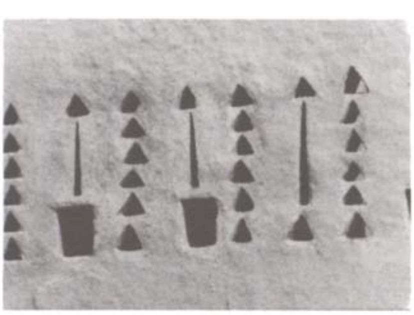
7. Example of stone keel arch construction typically used in mosque and public building construction.



8. Detail of typical column construction showing both footing and beam.



9. Detail of downspout (mirzam) construction.



10. Detail of the wall ventilation pattern on the Sa'ad Palace.

were generally restrained because of the prevailing conservative religious attitudes against ostentation. The vast, stark walls were subtly textured by the broad-toothed scrapers that were used to apply the wall plaster. Inverted solid projecting bands of triangular patterns were also used on the exterior surface both to decorate and deflect rain from the tall walls (see fig. 13).

Bright colors, in geometric and stylized patterns, were concentrated on the interior--doors, windows, and ceiling beams. Other interior decorations were reserved for only the most important rooms, particularly the *majlis* (the principal reception room for male visitors). Here it was not unusual to find fine white gypsum plaster with incised or pressed stylized flowers and geometric motifs.

Architecture as a Response to Climate and Culture

The Najdi climate heavily influenced the main architectural forms and choice of materials; the culture affected the overall planning, detailing, and decoration. Regional houses are generally two stories high, contiguous to each other along narrow streets. Where the street plan permits, houses are rectangular; however, it is more common for house forms to be irregular, imposed by the labyrinthine pattern of the streets. Dir'iyah is an example of this organic type of community where large groups of buildings are divided by narrow streets.

While little research has been conducted on Najdi town planning, fortunately Riyadh was documented in the late nineteenth century, and much of the original plan survived until the mid-twentieth century. Dir'iyah, while a ruin, largely survives in plan, enabling a comparison with Riyadh. The two capital cities share a variety of similarities. The concentration of houses was close to or surrounded the open squares that contained both mosques and markets, similar to the design that still survives in many rural towns. The plan of Dir'iyah has been succinctly described by Geoffrey King:

> Al-Dir'iyyah, the former capital of the Al Su'ud, is a special case, for as the center of a great state, its buildings, their numbers, their scale and the extent of the fortifications are all unusual. Nevertheless, on the main citadel, al Turayf, the main features of a Najdi settlement are still observed in what is a well-preserved 18th century town. Thus around the main mosque and an open area cluster the royal palaces and further out, the houses of lesser individuals. The whole was enclosed by walls. The plantations and palm-trees are still situated today below the main town in the wadi. Only its peculiarly strong position distinguishes al-Dir'iyyah from other towns in the area: in other respects it has the same basic features.[1]

This community form had many advantages with respect to both climate and culture. The narrow streets and courtyards provided pedestrians with protection from the sun and sandstorms. Attached buildings also limited the amount of wall surface exposed to the sun. With the fronts of houses on narrow streets, doors and other openings were carefully organized so as not to interfere with those of a neighbor. The result was cooperative communal interaction outdoors as well as privacy indoors for the inhabitants.

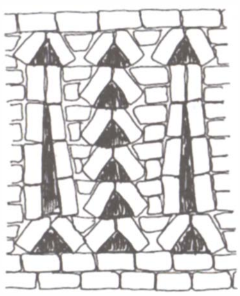
Building materials were also used as climate moderators. The combination of thick adobe walls as above ground shelter surrounding an open courtyard that provided light and ventilation helped keep the inhabitants cool in the summer and warm in the winter.

Equally unique are the cultural and spatial factors fostering a private lifestyle by providing outdoor space within the house--the introverted courtyard (atrium) (see fig. 16). Courtyard houses frequently accomodated an extended family built around single or groups of linked courtyards, they permitted the free growth of the family. Houses were often modified or enlarged to meet the needs of the occupants and were fortified in time of war.

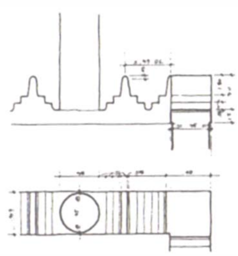
Historical Documentation

Few buildings in Dir'iyah, or any other small Arabian towns and villages, are mentioned in written documents before the mid-nineteenth century. The remoteness of these sites, the lack of a written tradition, and the preference of non-Arab visitors to record and discourse on the religious and social customs and habits rather than on the building arts make the documentation of specific structures virtually impossible until the development of photography in the mid-nineteenth century.

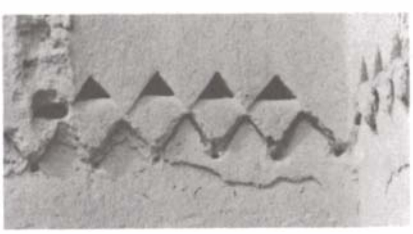
Known graphic documentation includes various sketch plans of towns that accompany the journals and accounts of visitors. Recorded more as a part of gathering political and military intelligence than for any interest in Arabian town planning concepts, only major physical sites and building complexes were noted. Surviving historic photographs include many individuals and groups of people or general views that only occasionally contain glimpses of structures.



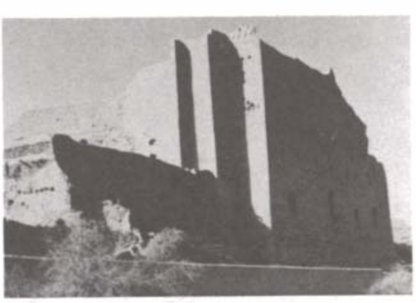
11. Construction detailing of ventilation pattern from the Mishari Palace.



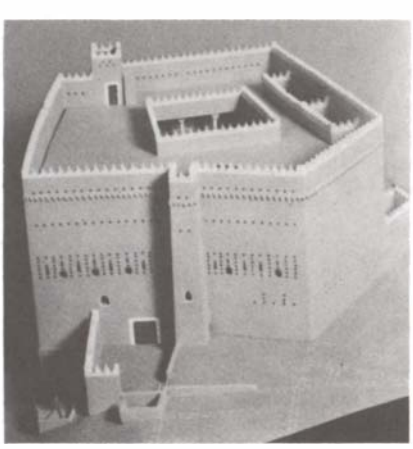
12. Typical decorative wall crenellation design.



13. Example of projecting triangle design used for both decoration and rain deflection.



14. The Palace of Omar as it currently exists as seen from the wadi.



15. Model of the reconstructed Palace of Omar.

Stabilization and Restoration Approaches

The stabilization and reconstruction plans prepared for the various structures were very conservative in their approach. These plans were sensitive to the integrity of the historic structures as well as to the materials and techniques of construction.

Several principles were established to guide the process. First, reconstruction or repair work would not begin until all the problems that had been causing the deterioration of the adobe had been determined, analyzed, and understood. Second, adobe building materials would be replaced or repaired with the same types of materials that were used originally. Similarly, traditional construction techniques would be utilized in the course of stabilization and reconstruction work.

A final principle was to resolve problems and retain original historic materials whenever. It was realized that the structures under investigation were "evolutionary" in nature, and when occupied they received on-going maintenance to renew protective adobe and gypsum plaster coatings. It was necessary to recommend the demolition of structurally unsound components and to reconstruct them completely with new, compatible materials. No uniform approach was possible, but every area of the structures was evaluated with respect to the extent of physical intervention necessary to achieve total reconstruction.

Where components of the structures no longer existed, reconstruction proposals were based on historical evidence or physical evidence noted in contemporary structures to allow for the accurate replication of missing features. The objective was to keep design speculation to an absolute minimum.

Although a wide variety of new materials, in particular surface coatings, additives, and waterproofing agents are available and have been tested, the results to date indicate that most, if not all, of these modern materials result in various forms of chemical changes, discoloration, or are incompatible with indigenous materials. Recommendations specifically ruled out the use of any new materials in the stabilization and reconstruction process, specifying only traditional materials and techniques.

Project Program and Documentation Techniques

Project contracts called for a multiple-phase program consisting of on-site analysis and testing; archaeological investigations; photographic and video documentation; architectural and historical analysis; preparation of four sets of documentary drawings--existing condition, proposed final configuration, demolition, and reconstruction; specifications; and bills of quantity. In addition, the project also called for several summary publications for use in site interpretation.

Archaeological investigations conducted as part of the site documentation were designed to delineate suspected portions of walls and columns. These were sometimes partially extant but were buried under debris from the siege and subsequent weather-related deterioration. Also documented were original finished floor levels. Once these features were determined, the overall clearing of the rooms and courtyards was undertaken.

Rough excavation work was conducted with pick-axe and shovel, occasionally with trowel and brush, and the rubble removed was monitored for the presence of artifacts, a few of which were recovered at each site. Searching for artifacts was not a significant component of the excavations because Dir'iyah's occupants were given the opportunity to remove their possessions prior to the devastation of the site.

The structures were visually and physically inspected to determine the physical condition and any structural problems. A room-by-room inventory and photo documentation was conducted to record material conditions, structural faults, and surviving design components. Also carefully reviewed were surviving examples of traditional building techniques, structural detailing, decorative elements, and finishes.

Our firms were involved in three projects at Dir'iyah--the Palace of Omar, the Subaalat and Mosque of Moudhi, and the walls and towers of the al-Turaif Quarter. Of these three projects only the al-Turaif fortifications have been completed. This project involved three towers, including the Faisal and al-Wasita Towers, two bastions, and several kilometers of walls.

The Palace of Omar bin Sa'ud (see figs. 14 - 19)

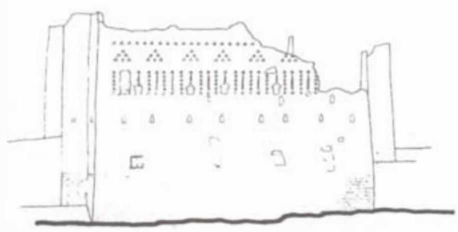
The palace stands in a prominent position high atop the wadi. While not the largest of al-Turaif's palaces, it occupies a prominennt site. From the greater extent to which it survived the 1818 siege, the Palace of Omar most likely served as one of a series of strongholds developed throughout the many lines of defense designed into the fortifications of Dir'iyah. The palace's adobe walls rise two stories above the tall stone foundation. The opposite side of the palace faces a narrow lane in a residential quarter of al-Turaif.

The palace has a five-sided plan built around a nearly square two-story courtyard (see fig. 16). The entrance connects with the courtyard, which served as the principal private outdoor space. Some unresolved research questions concerning this site remain to be resolved: (1) its potential access directly to the wadi below and (2) the design of a suspected service courtyard surrounded by rooms attached to the west side of the main structure.

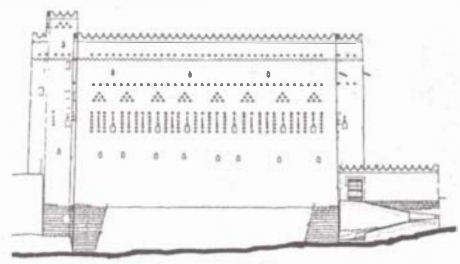
Omar bin Sa'ud was the son of Imam Sa'ud (the Great) who ruled over the state from Dir'iyah at its height. He was also the grandson of Imam 'abd al-'Aziz, who played a large hand in putting the state together. His older brother 'Abdullah became Imam upon the death of their father in 1813, and it was as a lieutenant of 'Abdullah that Omar fought in the fateful siege and battles of Dir'iyah in 1818.[2]

16. Existing condition ground floor plan of the Palace of Omar.

17. Reconstruction ground plan of the Palace of Omar.



18. Wadi elevation of the palace as it exists today.



19. Wadi elevation of the reconstructed palace.

The Subaalat and Mosque of Moudhi bint Ibn Wahtan (see figs. 20 - 25)

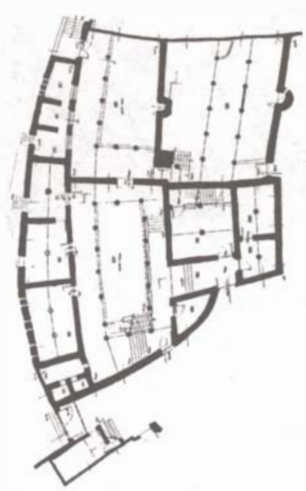
Located at the edge of the eastern residential section of al-Turaif, the subaalat and mosque structure was badly damaged during the 1818 siege. The subaalat, according to tradition, provided lodging for travelling merchants. It was a modest two-story structure built around a long, narrow courtyard. Several doors located along an adjacent lane provided temporary shop space for the merchants. The mosque connected to the subaalat was small and intimate, serving the immediate community around it.

The structure that we see today has been considerably altered over time. Formed from the components of earlier structures, probably one or more residences, the final configuration of this structure made it an unusual hybrid. The mosque itself was altered and rehabilitated during the mid-twentieth century when al Turaif was again inhabited.

20. The Subaalat and Mosque of Moudhi as seen from the wadi.

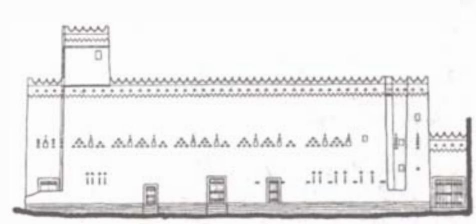
21. Interior detail of the Subaalat of Moudhi.

22. Existing condition ground plan of the Subaalat and Mosque.



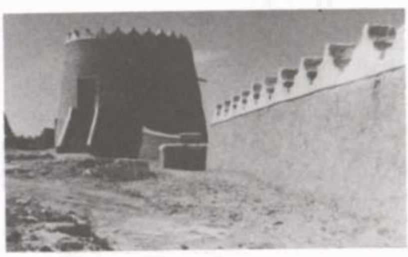
23. Reconstruction ground plan of the Subaalat and Mosque.

24. Existing east elevation of the Subaalat and Mosque.

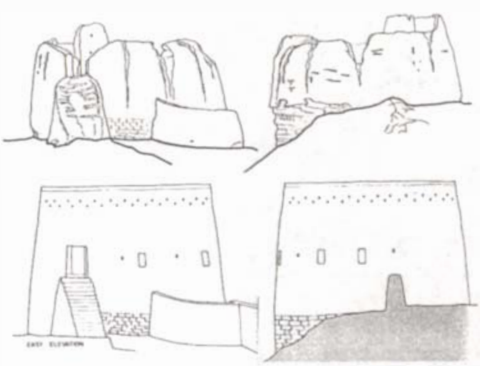


25. Reconstruction elevation of the Subaalat and Mosque.

26. Faisal Tower prior to reconstruction as seen from the wadi below.



27. The reconstructed Faisal Tower and part of the defense wall.



28. Existing condition (top) and reconstruction drawings (bottom) for the Faisal Tower.

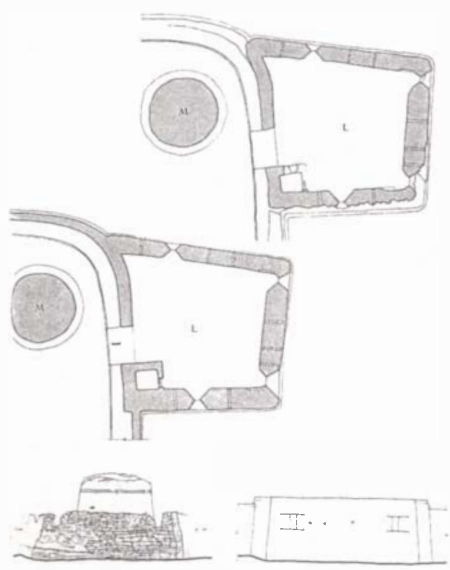
Moudhi was the wife of Muhammad bin Sa'ud, the first of the Saudi rulers to espouse the reformist cause of Muhammad bin 'Abdul al-Wahhab. Her intervention with her husband resulted in asylum being granted to the reformer and his followers, a fateful alliance upon which the success of the Saudi dynasty and the Wahhabi movement were based.[3]

The Al-Turaif Fortification Walls (see figs. 26 - 30)

The al-Turaif walls are one component of Dir'iyah's fortifications and are similar in design to fortifications at other locations in the region. The walls that surrounded Dir'iyah were punctuated by rectangular and circular towers at relatively regular intervals. These towers not only buttressed and strengthened the walls, they also served as observation posts and defensive positions for cannon. Special features of the al-Turaif walls are projecting rectangular bastions for cannons.

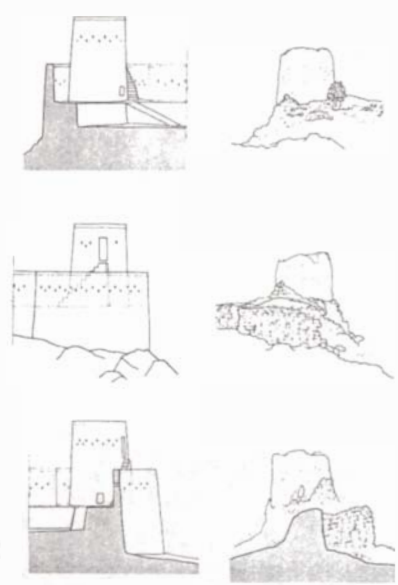
The al-Turaif fortifications are a combination of extensive rough-coursed stone construction combined with adobe brick for parapet walls. These were, nearly everywhere, finished with a coat of adobe plaster. The walls typically have a distinctive batter and vary in thickness. Major walls consist of outer and inner stone layers with an inner cavity of stone and rubble fill.

The walls had a rampart level protected by a tall parapet wall constructed of adobe bricks in which were found numerous small shooting and observation loopholes (*mizghal*). Fortification walls may also have had decorative stepped crenellations (*shurofat mudarrajah*) on the parapets.[4]



29. Existing condition and reconstruction drawings of a defense tower and bastion at al-Turaif.

30. Existing condition (right) and reconstruction elevations (left) of the al-Wasita Tower at al-Turaif.



Conclusions

With the rapid development and modernization of Riyadh, its suburbs (of which new Dir'iyah is one), and other parts of the Kingdom of Saudi Arabia, traditional historic structures are being demolished at an incredible rate, the intent being first and foremost to modernize the services and infrastructure of the Kingdom. In the midst of this, the preservation of the historic capital of Dir'iyah is being undertaken by the Department of Antiquities and Museums.

The mission of the department is to maintain, document, and, in selective cases, reconstruct significant historic structures at the site in order to interpret the three centuries of history of this site for current and future generations of Saudi Arabians. In interpreting a site of this scale and complexity it is easy to help the visitor to transport himself from the culture of the twentieth century to the reality of an historic city which was once one of the largest cities in the middle of the Arabian Peninsula.

The process of reconstructing significant examples of historic structures not only helps visitors to understand the past history of the Dir'iyah, the Najd, and the Kingdom through its building arts, it also results in new people being trained in the traditional methods of construction, preserving and passing on crafts and techniques to future generations.

NOTES/REFERENCES

1. Geoffrey King, "Some Examples of the Secular Architecture of the Najd," Arabian Studies VI, (1979): 116.

2. Michael Emrick, AIA, Carl Meinhardt, FAIA, and Jon Mandaville, The Palace of Omar bin Sa'ud (Riyadh: Department of Antiquities and Museums, 1989).

3. Michael Emrick, AIA, Carl Meinhardt, FAIA, and Jon Mandaville, The Subaalat and Mosque of Moudhi bint Ibn Wahtan (Riyadh: Department of Antiquities and Museums, 1989).

4. Michael Emrick, AIA, Carl Meinhardt, FAIA, and Jon Mandaville, The Walls and Towers of al-Turaif, (Nashville, TN., Department of Antiquities and Museums, 1983).

ABSTRACT

This paper is a brief case study of a preservation project at Acoma Sky City, a Native American settlement in New Mexico, USA on the National Register of Historic Places that has been continually occupied for more than 1000 years. A brief history is given, and the difficulties that are encountered when using federal funds to rehabilitate privately owned dwellings, are discussed. Recommendations are made for the planning of the rehabilitation of privately owned contiguous dwellings while maintaining a preservation perspective. Staged funding is recommended to obtain maximum value and minimal re-evaluation of priorities mid-project.

KEY WORDS

Adobe, preservation/rehabilitation, planning strategy, Native American tradition, historic heritage.

ACOMA: A CASE STUDY IN PRESERVATION PHILOSOPHY AND IMPLEMENTATION

Paul G. McHenry, Jr. AIA
Architect
4601 Montaño NW #52
Albuquerque, NM 87120
U.S.A.

Introduction

Acoma is a living monument and one of the unique treasures of North America. Its history and isolation from modern influences provide an unequalled opportunity to experience the past. The very qualities that make it unique also make its preservation more difficult. Preservation work at Acoma is subject to disciplines and pressures that are seldom encountered in preservation activities of this magnitude at other sites.

Acoma is a group of adobe and stone buildings located on top of a 350 foot high sandstone mesa, approximately 55 miles West of Albuquerque, New Mexico. The basic community pattern is comprised of three rows of house blocks, one to three stories high, oriented on an east-west axis. A monumental church is located south of the housing area. A valuable resource for restoration planners is the collection of Historic American Buildings Survey drawings, 1934.[1]

Acoma Sky City Area "C", ca. 1890 Museum of New Mexico Neg. # 16042

History

Although the precise chronological origins of Sky City are not known, is was an established community at the time of the first Spanish contact by Alvarado in 1540 AD. Its origins are believed to date several hundred years earlier, making it one of the oldest continually occupied settlements in North America. The earliest description of Acoma was given by Francisco Sanchez in 1581, where he reported finding "500 houses of 3-4 stories."[2] The 1980 Graham Report SKY CITY PLANNING inventories a total of 369 dwellings, 107 of which were recently constructed.[3] This indicates a 50% decline since 1581.

In 1598, in reprisal for the death of thirteen Spanish soldiers, Vicente de Zaldivar, organizer of the avenging company, ordered amputation of one foot from the body of every Acoma male over 25 years of age, enslaved all the Acoma people for 20 years, and razed the buildings of the community.[4] This severe punishment affected the Acoma community tragically and shocked the Spanish authorities, who later punished Zaldivar for his actions. His cruelty resulted in a distrust of outsiders which understandably persists to this day.

The next significant event was the resettlement of Acoma and the construction of a large church by the Catholic priest Fr. Juan Ramirez between 1629 and 1640. The form and pattern of the house blocks as they exist today were built at that time. The original Sky City dwellings reportedly were located in the vicinity of the present-day church.

Very little archaeological investigation has been done at Acoma, a situation common to most occupied pueblos. The culture and traditions of most pueblo communities make it unlikely that such investigations will ever be feasible unless undertaken exclusively by Indian personnel. The pre-Spanish buildings reportedly were of rubble stone, laid in mud mortar. Although this has not been proven, it seems likely that stone was the primary building material considering that, by most accounts, "adobe bricks" were introduced by the Spaniards. However, if stone was the building material of the 500 dwellings that were destroyed by Zaldivar in 1598, what happened to the stone? No significant accumulation of stone has been found, either in building walls or at the base of the cliff. Reportedly, some, if not all, may have been used in the construction of the retaining wall at the "campo santo" (graveyard) on the east side of the church. The Acomas are very sensitive about the disturbance of burials, so there is little likelihood that any further investigation will be allowed.

The earliest use of adobe bricks at this site was in the construction of the church, where a brick size of 10" x 19" x 3" was used [5]. This same brick size is found in the wall construction of the areas of Acoma presumably built during or after the construction of the church. This dating was further established by tree ring studies by the University of Arizona, which indicated that virtually all timbers in one house block (Area "C") were cut in 1646 [6].

The soil source for the adobes and the site of their fabrication has not been determined. Quite possibly, the bricks were made in the valley below and were transported to the top of the mesa after manufacture. There is very little, if any, naturally occurring soil or water for making bricks on top of any of the nearby mesas, so we may presume that Acoma was the same. Although no precise estimate has been made, hundreds of thousands of bricks were required. Adobe bricks are very heavy (100 lbs per cu. ft.) It would be more practical to carry only the weight of the finished bricks up to the construction site rather than soil and water, which would then evaporate after drying. Soil samples were taken from building walls and plaster, analysed for minerology and compared with several possible soil sources in the vicinity, but the results were inconclusive. Perhaps the variable nature of any given soil source makes precise determination impossible; this factor is another complication in developing adobe restoration techniques.

Preservation Goals

Acoma is a time capsule of a 16th century native culture that has been relatively undisturbed. It must be preserved as intact as possible so that the wealth of information it contains will not be lost. Some features have already been lost through neglect and modification by their owners. New doors and windows, cement stucco, and other modern features represent improvements in the mind of the owners, who may fail to see the historical value of the original structures. When restoring public monuments or property, preservation teams can apply their principles of restoration ethics with free rein. But Acoma is private property, and the owners have the right to make the final determination. The values for preservation of this resource are manifold:

1. Prevent loss of historic examples and the cultural heritage they represent to further the Acoma's understanding of their own heritage and educate other cultures.

2. This resource has great economic value to the Acoma people. Its continued preservation provides tourist dollars, a primary income source for the pueblo. Many village leaders are aware of this, and the cultivation of preservation attitudes can only be accomplished with their help.

3. The age and lack of maintenance of many of these buildings has created a safety hazard to both occupants and tourists which must be mitigated.

4. The construction work required for the preservation and continued maintenance of these buildings represents a source of employment for the Acoma people, and makes use of their natural resources of stone, wood and earth.

5. As there is constant turnover in construction personnel, it is desirable to devise a logical, standardized plan for a system of maintenance, repair and reconstruction which reflects historic detailing. This could be used for future guidance for the Acoma community.

Implementation Problems and Conflicts

For several years, the United States Department of Housing and Urban Development has offered annual Community Development Block Grants for housing rehabilitation to Native American communities on a competitive basis. Conditions of these grants provide that work on historic buildings follow The Secretary of The Interior's Standards for Rehabilitation [7], in order to preserve and protect historic resources.

Acoma is a special case because it is an occupied community owned by individuals, as compared to a ruin or monument that is not privately owned. The grant program under which this rehabilitation was to be done was a Community Development Block Grant, presumably conceived for more conventional housing which would not have the historic restoration complications presented by Acoma. The responsibility for overseeing the application of the "standards" was delegated to the Historic Preservation Division of the New Mexico State Office of Cultural Affairs.

In the past (1983-85), several problems developed during funded projects at Acoma. Asphalt emulsion stabilized (waterproof) adobe bricks were used for reconstruction and repair is one example. Although the Acoma builders believed this material to be a more durable brick than the original plain mud type, the final wall finish was to be of natural mud plaster, which would not adhere to the asphalt surface, and eroded in a matter of weeks. Other non-historic features installed without prior official approval were wall buttresses placed to reinforce sagging historic walls. Window groupings that had no historical justification and modern style doors were installed. In response to these problematic alterations, the Historic Preservation Division required that Acoma Pueblo employ an architectural consulting firm experienced in preservation and skilled in adobe technology. The author's firm, Paul G. McHenry, Jr. and Associates, Architects, was selected to mitigate past mistakes and to provide guidance and supervision for the future reconstruction and rehabilitation of Area "C", one of a number of designated areas at Acoma.

Mud plaster erosion from asphalt stabilized adobe bricks.

Architectural elements without historical background; buttresses and side by side windows.

Preservation standards related to these projects were affected by the following factors:

1. The Acomas are a proud and independent people who strongly resist any efforts to control or influence them, and they view Acoma as their private domain. Outsiders are not welcome except as tourists or personal friends. Many of their religious activities exclude outsiders, and very few outsiders are welcome within the buildings. The crew that prepared the Historic American Buildings Survey noted this fact in 1934 and that access to some of the rooftops was limited as well.

2. Many of the Acomas do not live on the mesa top full time, and have homes in the valley below, closer to their farms and work, so the historic houses are used more for special ceremonial occasions than as primary residences. As a result, individual homeowners were not always readily available for consultation about preservation details for their home, although a growing number of families are living at Acoma on a full time basis. Individual homeowners were not always sympathetic with preservation ideals, and they want to install modern amenities of their own choosing.

3. The affairs of the pueblo are managed by a Governor and tribal Council who are elected each year. The Cacique is the religious leader. It is interesting to note that although the tribal officials are all male, Acoma is a matrilineal society, so title to the home is held by the woman of the family.

4. The budget for rehabilitation as originally conceived by tribal planners was intended for the employment of tribal members, so any expenditure outside the pueblo was strongly resisted.

Resolution

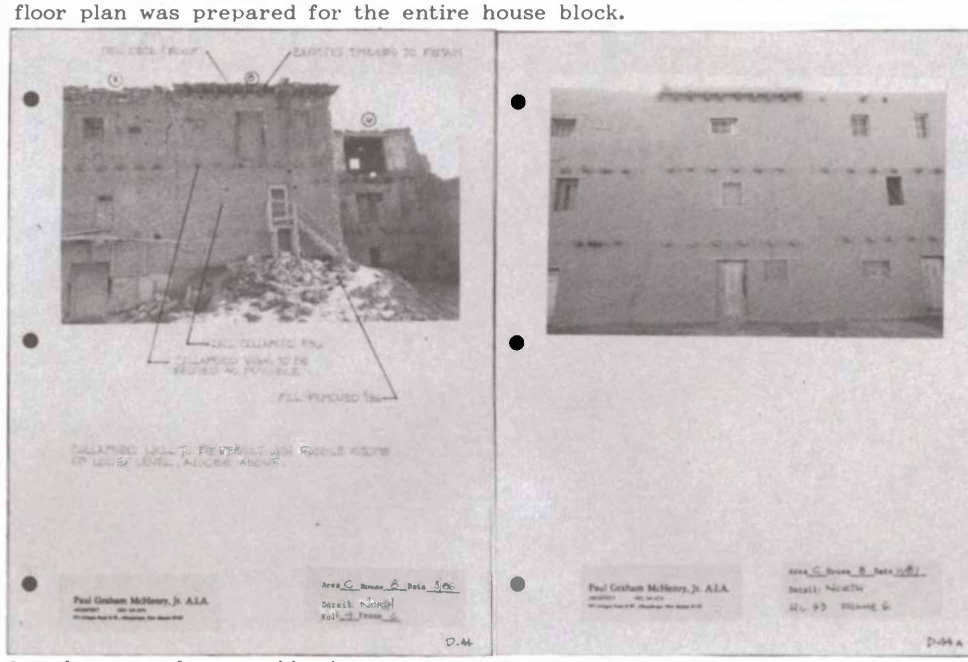
The primary conflict in the implementation of this project was one of attitudes: a resentment by the Acomas when they were told by preservation oversight authorities that they must do the rehabilitation in a certain way or lose their funding; a lack of sensitivity on the part of historic preservation authorities to the needs and desires of the private owners, to which the owners were entitled.

Initially, a common attitude on the part of the Acoma leaders was that they knew more about their building technology than outsiders, and unfortunate past experiences with "expert" consultants had reinforced this attitude. They did not realize that, although many of the construction crew were skilled in modern building techniques, their earthbuilding skills had been diminished or lost through time and lack of use.

The problem of the mud plaster and asphalt bricks could not totally be resolved, but an improved and more durable mixture was developed. Bruce McHenry of the architect's staff, an expert on mud plaster, discovered that the soil mixture being used was faulty: the main ingredient was "blow sand". The rounded particles of blow sand (as opposed to the angular particles of "sharp sand") would not interlock with each another to create a consolidated mass. By the substitution of coarser, more granular sand particles, which the Acoma crew called "gravel", a much more durable mud plaster could be achieved. Through experimentation, demonstration, and the active involvement of the architects, staff, and construction crews, many lost skills were regained by the Acomas and a team effort was created.

A major point of disagreement and conflict was the retention of the earth floors on the upper levels. These were historic features of great interest, and which had value in an archaeological context, but the owners did not want dirt floors. The floors were unpleasant to live with, smelled terrible when disturbed, and were unsanitary, carrying the refuse of centuries. The final result was that many earth floors were removed. Construction scheduling and lack of proper budgeting dictated that only minimal archaeological investigation would be done. The archaeology was done by an Acoma archaeologist with only a few weeks training, and who received only minimal cooperation from the construction crews. The archaeologic investigation consisted of a small number of test pits and the stockpiling of the earth material removed for later examination. Artifacts found were returned to the home owners for their disposal. The conflicts could have been mitigated by additional planning and consultation leavened with sympathetic attention to the owner's needs.

In order to minimize the costs required for architectural planning and documentation and to meet the Standards, an innovative approach was required. A simple photo and drawing scheme was proposed by the architect to create a project "workbook" with pages for each individual house. The photography was done at minimum expense using 35mm black-and-white film. Each photo used for the workbook was enlarged to a 5" x 7" print and mounted on an 8-1/2" x 11" sheet of paper which was incorporated in the work book. Additional photos were taken of significant interior details and elevations after completion to provide full photo documentation. A floor plan and front/rear elevations were drawn approximately to scale for each level of each house, prepared from aerial photos and limited field measurements. These were grouped in sections of the workbook appropriate to each house unit. An overall elevation drawing and floor plan was prepared for the entire house block.



Sample pages from workbook.

Originally each detail required approval by the New Mexico Historic Preservation Division Office prior to construction. The the difficulty in gaining entrance to individual houses, obtaining the advice and approval of the owner, and construction scheduling made this unworkable. Therefore, a plan was adopted to request approval in principle of the overall plan, with smaller details left to the discretion of the architect and the construction foreman.

Additional sections of the workbook included standard details of expected repairs common to several buildings, drawn in an isometric style for easier understanding by the construction crews. A section for historic photos was created with suggested approximate photo points. Before and after photos also proved beneficial. This system accomplished two necessary steps: documentation of condition of the monument, and simple directions for repairs and improvements at minimal cost and complication.

The participation of individual homeowners in determining the nature and extent of preservation of their homes was paramount. As individual homeowners, they are entitled to do anything they wish to do using their own funds. There are no regulations to control the owner's choice of style or architectural elements at this time, although community leaders have debated the merits of such a regulation.

In order to achieve maximum results in historic preservation for this and future projects, it was vital to seek the support of the construction crew leaders. Preservationists take the position that as this work is being done with Federal funds, the Acomas could be told exactly what they must do. What was overlooked was the fact that this was a "rehabilitation" project to improve the safety and livability of these peoples homes, as compared to a "preservation" project, which would have much more stringent disciplines.

Area "C" north side, before rehabilitation.

With the approach taken, most of the preservation goals were achieved, and the substance of the resource preserved. Unfortunately, some historic features were lost or replaced, such as adobe walls, doors, and windows that were considered unrepairable. Salvage was claimed by the owners, who disposed of it as they saw fit. Most of the original dirt floors were replaced at the insistence of the owners. This change was generated for sanitation reasons, and could be partly justified by the fact that these were interior features which would not be seen by the public.

The Secretary of the Interior's Standards for Rehabilitation is a remarkable document in that it wisely anticipates and provides for resolution of conflicts such as were experienced on this project. Key phrases in the ten "standards" include: "...every reasonable effort...,...avoided when possible...,...may have taken place...,...wherever possible...", etc.

Conclusions and Recommendations

1. A clear choice must be made during the planning stages of a historic site project between "Historic Preservation" and "Rehabilitation" standards, which are very different approaches. The former not only implies, but requires heroic measures which can be very costly, and the latter provides some practical flexibility. Perhaps the only suitable subjects for true historic preservation are those owned by a government agency, or whose title and control are held by an entity dedicated to its pristine preservation without regard for personal profit or third party motives.

2. Funding for any preservation/rehabilitation project should be made available in two discrete phases. The first phase should include funding for detailed investigation and determination of probable costs by qualified personnel or consultants. The second phase provides funding for the actual project, and should include contingency allowances. Such dual phase funding would allow a realistic assessment of probable costs and alternatives prior to determination of final goals and costs. Unfortunately, funding for many current projects is allocated prior to the determination of specific goals, and the competition for these available funds can skew the final results unnecessarily.

3. Local zoning laws, regulations or recommendations should be established and put in place by the people who would benefit, so that it would not be viewed as outside interference in local affairs.

Notes:

1. Peter Nabokov, Architecture of Acoma Pueblo (Santa Fe: Ancient City Press, 1986)

2. Ward Alan Minge, Acoma, Pueblo in The Sky (Albuquerque: The University of New Mexico Press, 1976), 14

3. Channel Graham Architecture, P.A., Sky City Planning, a report commissioned by Acoma Pueblo, (Albuquerque: 1980) (Tribal archives)

4. Minge, "Acoma", 20

5. Minge, "Acoma", 21

6. William J. Robinson, Tree Ring Studies of the Pueblo of Acoma, Preliminary Report (Tucson: Laboratory of Tree Ring Research, University of Arizona, 1987) Table 1.

7. U. S. Department of the Interior, National Park Service, The Secretary of The Interior's Standards For Rehabilitation (Washington, Revised 1983)

THE STUDY OF ACCELERATED CARBONATION OF LIME-STABILIZED SOILS

Mário Mendonça de Oliveira * - Cybèle Celestino Santiago and Sílvia Pimenta d'Affonsêca
Faculdade de Arquitetura da Universidade Federal da Bahia
Rua Caetano Moura, 121 - Federação
40.210 - Salvador - Bahia - Brasil

ABSTRACT

Traditional mud brick technology represents an attractive alternative in the construction of low-cost structures.

Lime is one of the oldest substances used to stabilize earthen materials. Nineteenth century lime-stabilized mud brick found in Bahia has been subjected to laboratory analysis. Since analysis of lime -- $Ca(OH)_2$-- containing materials is difficult due to the slow time course of the carbonation process, a method of reducing the reaction period from months to a few days has been developed. This process has been used to test adobes stabilized with lime.

KEYWORDS

Soil-lime stabilization, accelerated carbonation, mud brick, earth walling, adobe, restoration of earthen materials.

Introduction

It is commonly assumed by those people who study the history of architecture that wood and mud were the first building materials to be used by men. Mud, which is a very cheap material, has been continuously used in many different and simple ways: by throwing it against a rudimentary frame made of wooden sticks, as amorphous mud bricks, as plano-convex adobe bricks [1], as lath-and-plaster wall, "pisé de terre", clav stuccoes, etc. Although these techniques were sometimes ephemeral, according to Vitruvius they had great prestige (especially in the case of adobes). [2]

The low cost of earthen constructions is important when developing alternative building techniques particularly in third world countries.

The performance of soil building materials depends not only on the composition of the minerals that constitute them but also on the granulometry of the aggregates, on the rate clay/inert materials and on such factors as the percent moisture content of the mixture.

The studies and analysis of ancient earthen materials demonstrate that our ancestors were familiar with the use of that technology. By experience and tradition, they were able to produce materials of good stability with an optimal distribution of particles.

In Brazil, the use of simple building techniques with earthen materials dates from the colonial period (sixteenth century). Contrary to other native peoples in the Americas, Brazilian Indians were not very familiar with earthen materials. They preferred wood and palm leaves as building materials. Old documents contain much information concerning the use of lath-and-plaster and "pisé de terre". These documents describe the preparation of a plastic mixture of clay, aggregate, and water which was then thrown against a frame of horizontal and vertical sticks of wood, tied with liana or, rarely, with leather ropes. This technique is still used today by poor people (who make up the majority in Brazil) living in the country and in the peripheral areas of cities.

Salvador, the first national capital of Brazil, was founded , in 1549. At the beginning, a wooden fence protected the city, but as it was very weak, the wood was later replaced with "pisé de terre", a technique as old as the lath-and-plaster wall. Unfortunately, the second wall did not last long in the tropical rains and it too has disappeared.

Friar Jaboatão, a well-known chronicler of early Brazil, has described the walls which surrounded the city of Salvador as "made of good and thick earth wall".[3] Nevertheless, it seems to us that he alone believed in the quality of this wall. Gabriel Soares, another chronicler from Brazil, for instance, wrote that "the walls have crumbled because they had been constructed in pisé de terre". [4]

Luiz Dias, the master of works responsible for the planning and construction of the city of Salvador, did not have much faith in the efficiency of these walls. We reach this conclusion from comments he made in one of the letters he sent to Portugal: "using the dart I had in my own hands I was able to destroy them very easily. He has also pointed out that the walls were much too high considering the fact that they had been made in pisé de terre without lime". [5] This comment confirms that lime was used as a stabilizer since the beginning of colonization. This method of construction was brought by the Portuguese to the colony. The "technological appropriation" [6] of an old tradition is fundamental to our research. In general, there is no reference in the history of architecture in Brazil to the use of lime as a stabilizing element. "The use of the technique of pisé de terre was more diffuse in the states of São Paulo and Goiás [7], but it was also used in Minas Gerais and Bahia. In Salvador (Bahia), it was

* Author to whom correspondence should be addressed

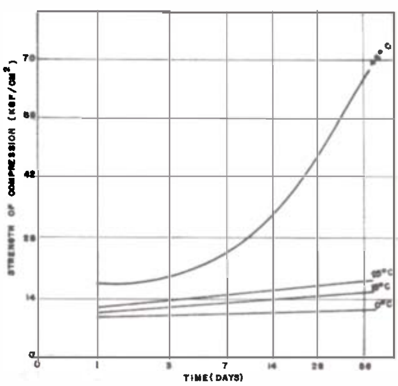


Fig. 1 - Effect of time and temperature in the process of soil-lime stabilization. 5% $Ca(OH)_2$

used primitively in its walls and other constructions. Later, this technique was put aside and replaced by the lath-and-plaster technique, which is simpler to execute. Nowadays, it is very difficult to find craftsmen ("taipeiros") who know the method of building in "pisé de terre".

In ancient times, the use of adobe was also very common throughout Brazil. Even though its use still persists in the construction of low-cost houses, people prefer to build their houses using lath-and-plaster.

Soil Stabilization

The study of soil stabilization in the conservation/restoration of monuments and archeological sites is very important. It is also appropriate to the construction of low-cost buildings. Portland cement was responsible for the introduction of a very efficient stabilizer in construction. On the other hand, its use in conservation must be very restricted. This is because it contains soluble salts, which can be dangerous to the monument. Also because its high strength is incompatible with earth. It is necessary, therefore, to use a stabilizer for coating the tops of walls, ruins, and other earthen structures to increase durability. There are additives of traditional or modern use (cattle dung, sugar, straw, blood, etc.) that can also be employed.

The use of cement has spread since last century. In Brazil, for example, modern architecture is based on the use of this material. In addition to the disadvantages mentioned above, there is also the problem of supply. The opposite is true for lime. It is much simpler to prepare and, in some areas of the country there are numerous lime quarries and still a rudimentary production of the material is possible.

It is interesting to note that in spite of not being completely understood by the specialists until now, the process of soil stabilization with lime is considered by them as technologically and culturally adequate in the conservation/restoration of earthen structures.

It stands to reason that in a single mixture of soil and water -- as is the case with adobes, "pisé de terre", and lath-and-plaster walls -- the reactions are dependent on the activity and surface area of clay particles. The smaller the particles, the more reactive they are. Thus, clay particles are more reactive than larger silt particles. Sand grains are bigger than the latter and are inert. In the case of soil-lime, some characteristic chemical reactions occur. Some of them are directly related to the laminar structure of the clays and to the distance between strata. This means that the reactivity of the product will change as a function of the kind of clay that predominates in the soil and the spaces between the layers.

"In the presence of water, the cations (mainly Ca^{++}, and sometimes Mg^{++}) originating from the lime cause the saturation of the clay minerals in the soil. Thus, the properties that depend on the charge and the superficial status of the particles (limits of consistence) are suddenly modified. In some aspects, the interchangeable cations enjoin the bonds between the clay particles and the way they gather, modifying their hydric-mechanic behavior". [8]

"The reactive phenomenum causes the appearance of silicates, aluminates and aluminum-silicates of hydrated calcium, substances that present cementing conditions. Specialists suggest that some of these reactions happen suddenly". [9]

Other reactions occur after longer periods of time. In all cases, time and temperature have a direct influence on the reactions (Fig. 1).

A symposium on soil-lime was recently held at CEPED. [10] The specialists divided the phenomena of stabilization in two groups:

a) Fast reactions
- . Cation exchange
- . Absorption of $Ca(OH)_2$ molecules
- . Ion crowding

b) Slow reactions
- . Siliceous cementation
- . Aluminous cementation
- . Ferreous cementation
- . Carbonation

We have developed at the NTPR [11] a process of accelerated carbonation in lime-containing mortars. Our intention now is to apply this process to verify how the phenomenum of carbonation contributes to the process of stabilization increasing the mechanical characteristics of the soil. Carbonation is one of the slow reactions that occur when stabilizing a soil with lime. Thus, accelerating this process we will save time when observing the phenomenum.

Time is not as important as temperature (Fig. 1) in the development of mechanical strength in the first phase of the process of lime stabilizing soils (fast reactions). As the slow reactions need years to be completed, the effects of carbonation will only be noticed after a long period. Then, it is very important to our research to speed these reactions in order to get through the first results in a short time.

The Stabilized Adobes from Cows' Island ("Ilha das Vacas") in Bahia

We have been in charge of the restoration of a nineteenth century house located on Cows' Island. During the survey that preceded the restoration of this building, we were lucky to find an internal wall made of mud bricks. This discovery aroused our curiosity because initial inspection suggested that the adobes had signs of a lime additive.

A spot test was conducted in our lab. It proved our field observations to be correct. The bricks contain a very precarious lime that was probably prepared "in situ" by crushing and burning seashells. In the "Recôncavo", an area in the "Todos os Santos" Bay, Bahia, there was a tradition of using seashell lime. [12] This is a product of high quality, although there is the inconvenience of the presence of soluble salts if the material is not well washed. As we have found some pieces of shell within the ancient adobe, we can assume that the shells had not been well burned.

Historical research provides us with documentation on the use of lime-stabilized soil in Bahia (e.g., Mr. Dias' letter). This is the first discovery of an actual sample supported by further laboratory analysis.

Although the text written by Prof. Silvio de Vasconcelos is considered a classic on the history of building materials in Brazil, there is no reference to the use of lime as a stabilizing additive. He mentions other additives, odder than that one: "For that reason, it is possible to find dung (basically from bullock cattle) mixed with vegetal fibers or animal hair, in order to reinforce the mud with an interior frame. There is also the tradition of the use of ox blood as an agglutinant element". [13]

According to the historical record, the stabilized mud bricks we found also belong to the nineteenth century.

The characteristics of the material we have found are the following:

Bulk density - 1,806 g/cm^3

Granulometry:		ASTM	ABNT (Brazil)
Gravel		13%	5%
Sand	Coarse	9%	8%
	Medium	13%	12%
	Fine	22%	34%
Silt		22%	16%
Clay		21%	25%

Classification:
USCS: SC AASHTO: A-6 (3)
USCS: Unified Soil Classification System
AASHTO: American Association of State Highway Transport Officials
WL = 32% (liquid limit)
WP = 19% (plastic limit)
IP = 13% (plasticity index)
Percentage of $CaCO_3$ = 20.54
pH= 8.38. It indicates that almost all the calcium hydroxide used in preparing the bricks had been carbonated, i.e. converted into calcium carbonate by reaction with carbon dioxide from the atmosphere.

The Process of Accelerated Carbonation

It is obvious that the carbonation of calcium hydroxide always presents a problem when performing laboratory analysis. Thus, we have developed in the NTPR a very simple technique for carbonating lime-containing samples. The fundamental ingredients are CO_2 and

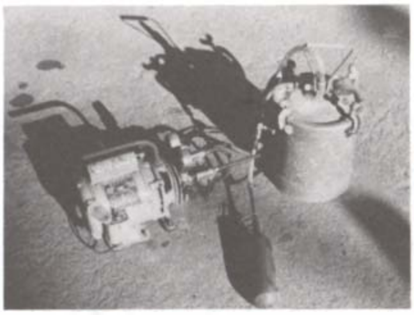


Fig. 2 - First prototype of our accelerated carbonation chamber

Fig. 3 - Second prototype of the chamber

water. In order to accelerate the process of lime carbonation, an hermetically closed carbonation chamber was created (Fig. 2, 3). Our first prototype was a pressure container used for painting, which had a metal frame inside to support the samples. In order to maintain an atmosphere saturated with water vapor, it was necessary to provide a layer of water below the frame. A vacuum pump was used for twelve hours in order to remove the air from inside the pores of the samples. Then the pressure was stabilized allowing the introduction of CO_2. We used gas from fire-extinguishers, so the costs of the equipment and the operation were very low.

The efficiency of the process can be proved through the results below: .

LIME / SAND	REACTION TIME	STRENGTH Kgf / cm²	
1 : 2	4 months (normal exp.)	7.00	11.78
	6 months (normal exp.)	23.20	11.83
	acc. (15 days)*	64.15	53.24
1 : 3	4 months (normal exp.)	9.34	9.30
	6 months (normal exp.)	18.05	14.72
	acc. (15 days)*	27.55	29.07

* Humid, in a high CO_2 concentration.

Soil from CEPED

WL = 45,2%
WP = 20,7%
IP = 24,5%

SAMPLE	REACTION TIME 12 days	STABILIZER	STRENGTH Kgf/cm²	OBSERVATION
A	stove (35°C)	---	5,34	
B	stove (35°C)	8% $Ca(OH)_2$	9,40	
C	accelerated-CO_2	8% $Ca(OH)_2$	18,43	acc. 5 days

Analysing the samples before and after the carbonation process, no substantial change in color has been recorded. From our point of view, the small changes that are noticeable will be useful for characterizing the intervention, as is normally required for doing any restoration work.

Conclusions

The use of lime as a stabilizer of earthen structures is admitted with other stabilizers because it is a "technological appropriation" of an old tradition; it makes possible the use of local labor; and it improves the mechanical characteristics of the material.

There should be no substantial changes in texture and color of the adobe if lime is used in a low percentage -- 3 to 8 % -- as recommended by CRAterre. [14]

According to specialists, the function of lime when stabilizing soils is basically connected to the reactions with clay minerals. In addition to this, we have observed that the carbonation process is also remarkable to the increase of mechanical characteristics of stabilized soils, despite the use of small quantities of lime.

Acknowledgements

We thank André Lyra and Prof. Luis Carlos Dourado (NTPR), CEPED, "Laboratorio de Geotecnia" - Engineering School (UFBa), Gilda Sento Sé, Prof. Carter Hudgings and Fernando Santiago Jr. for their collaboration.

Notes and Citations

1. N. Davey, A History of Building Materials (London: Phoenix House, 1961), 22.

2. Vitruvius, "Book II", Vitruvius on Architecture (edited from

the Harleian Manuscript 2767 and translated into English by Frank Granger), vol. 1 (London: Harvard University Press, 1962), 117. "Therefore in some cities we may see both public works and private houses and even palaces built of brick" .... (mud brick).

3. A. S. M. Jaboatam, Fr., Novo Orbe Serafico Brasilico ou Chronico dos Frades Menores da Provincia do Brasil (printed in Lisbon in 1764 and reprinted by authorization of the "Instituto Geográfico e Histórico do Brasil"), vol. 1, (Rio de Janeiro: Typ. Brasiliense de Maximiano Gomes Ribeiro, 1858), 125.

4. G. S. de Sousa, Notícias do Brasil (comments and notes by Varnhagem, Pirajá da Silva and Edelweiss. Print financed by the Departamento de Assuntos Culturais from MEC), cap. 7, (São Paulo: MEC, 1974), 65.

5. E. Carneiro, A Cidade do Salvador: 1549; uma reconstituição histórica. 2 ed. (Salvador: Gráfica Económico, w.d.), 65.

6. A. Alva and E. A. Chapman, Appropriate Technology? in Appropriate Technologies in the Conservation of Cultural Property (Paris: Unesco, 1981) 115-134.

7. S. Vasconcelos. Arquitetura no Brasil: Sistemas Construtivos.5 ed. (Belo Horizonte: Universidade Federal de Minas Gerais, 1979), 21.

8. M. T. Nobrega, Relações dos Argilos-Minerais com Cal, in V Reunião aberta da Indústria da Cal. (São Paulo: Associação Brasileira de Produtores de Cal) Bulletin no. 14 (1985): 63.

9. S. Diamond and E. B. Kinter, Mechanisms of soil-lime stabilization. An Interpretative Review. High Research Board Rec. no. 92 (1965): 83-102.

10. The Center for Research and Development. A research facility joined to the Goverment of the state of Bahia, Brazil

11. The Technological Center for Preservation and Restorarion (NTPR) is a structure joined to the Federal University of Bahia and to the National Heritage Institute. It is responsible for analysing building materials and developing restoration researches and projects.

12. G.S. de Sousa, Notícias do Brasil, 160. "And there are so many oysters in Bahia and in other parts that it is common to load huge boats with their shells in order to prepare lime. Lime which is prepared from these shells is very good for building purposes. It is also very white".

13. S. Vasconcelos, Arquitetura no Brasil: Sistemas Construtivos", 20.

14. P. DOAT. et outres. Effets de la stabilisation a la chaux. In: Construire en Terre. (Paris: CRAterre, 1985), 212.

RESTORATION OF THE SIXTEENTH CENTURY CHURCH AT CURAHUARA DE CARANGAS, BOLIVIA: A CASE STUDY

Carlos Rua and Anton Rajer
1508 South 14
Sheboygan, Wisconsin, 53081
USA

ABSTRACT

Curahuara de Carangas is located 4,000 meters above sea level in a remote area of the Bolivian altiplano near Chile. This adobe structure consists of a single long nave and three smaller rooms. The thick walls are supported by massive buttresses. Interior surfaces are covered with Biblical murals in tempera on lime wash. Some are dated 1608; others bear the signature and date, " Ignacio Martine de Lima, 1777."

Local Indians have provided care and preservation for centuries. However economic changes have led to the church's deterioration. In 1984 the Bolivian Institute of Culture, with UNESCO support, began site preservation in a project that incorporated local workers into the church's restoration. The churchyard was cleared; the wood, reed, and thatch roof reconstructed; and the adobe walls stabilized and whitewashed.

The project combined efforts of architects, art conservators, and local craftsmen who are descendants of the original builders. Work was carried out using traditional skills originally used to construct the church.

Murals were consolidated with polyvinyl alcohol and Acryloid B-72 and cleaned with soft erasers. A sensitive approach was taken with respect to exterior structural forms and interior decorative schemes, while meeting the community's need for a functioning church.

KEYWORDS

Bolivian Altiplano, Colonial Architecture, Adobe and Mural Conservation, Acryloid B-72

Located on an arid high plain in the western region of Oruro, Bolivia, the sixteenth century adobe church at Curahuara de Carangas lies at 4,000 meters above sea level. The area has been occupied since pre-Columbian times, when the area's population density was higher than it is now.

Decoration and Importance

One great value of the church at Curahuara lies in the fact that its entire interior is decorated with murals. Virtually hundreds of square meters of walls and ceiling are painted in a medium of tempera on lime wash. The murals in the presbytery are dated "1608." Others in the church bear the signature and inscription "Ignacio Martine de Lima 1777." The oldest and most complete group of their type preserved in the South America, the murals constitute an important monument of Bolivian cultural patrimony. Pictorial themes derive from the Bible, such as scenes of the Last Judgment, the Flood, and the expulsion of Adam and Eve from the Garden of Eden. Ceiling decoration consists of portraits of the 12 apostles and Christ in the presbytery above the altar (the 1608 murals) and floral decoration elsewhere (see figure 1).

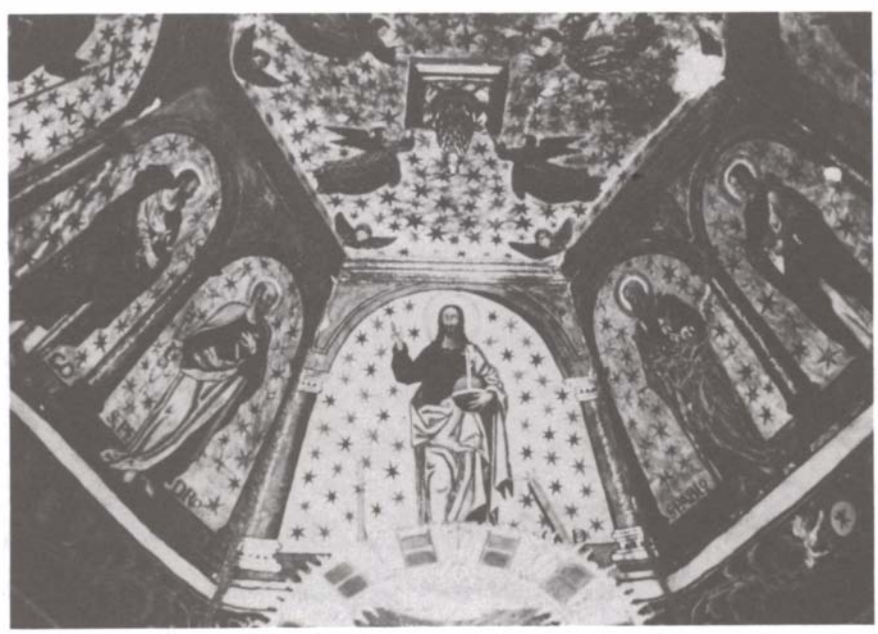


FIGURE 1. Ceiling decoration portrait of Christ flanked by the apostles.

Materials and Construction

Mud brick has been used in this area for centuries, as attested by nearby pre-Incan tombs constructed of the material. The site of the church at Curahuara is slightly sloping, with a 2 percent grade from east to west. Built at the end of the sixteenth century, this is a typical Renaissance church of the early Spanish colonial altiplano period. The interior consists of a single long nave, a sacristy, a baptistry, and a presbytery. A separate bell tower stands within the churchyard (see figures 2, 3).

The thickness of the church's walls varies greatly but tends overall to be approximately 1 meter. Some of the buttressed walls are 4.5 meters thick, including their supports. The standard size of the original bricks is about 30 cm x 60 cm x 6 cm. At the time of construction the exterior and interior walls were covered completely with lime wash. The roof is made of wooden beams with reeds and bamboo affixed to them; thatch forms the outer layer. In addition, the buttress tops were covered with a type of reed "shingles" to reduce weathering.

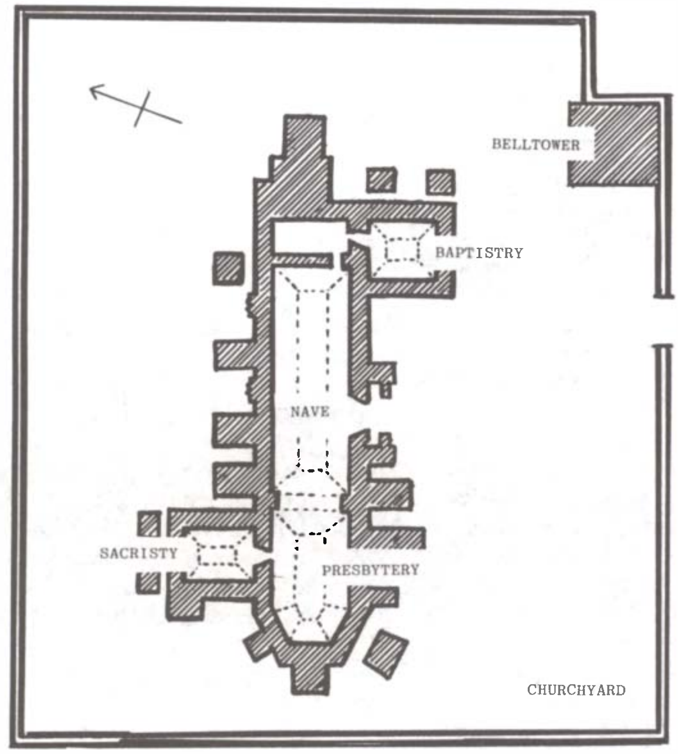


FIGURE 2. Plan of the church at Curahuara de Carangas.

Historical upkeep and restoration strategy

Construction of the church in colonial times was accomplished by workers from ten local Indian communities. Throughout the centuries these same communities were charged with the church's care in perpetuity and have continued it to this day. However, the church has fallen into disrepair in recent decades because of declining population and an exodus from this impoverished rural area. Remaining members of each of the ten communities have taken responsibility for the upkeep of a specific part of the building, such as the entrance portal or the baptistry. This system of care and upkeep was integrated into the recent restoration project: each community was responsible for restoration work on their assigned portion of the building, under direction of the Bolivian Institute of Culture (IBC) architect. Thus this project was unique in that it employed descendants of the original builders to carry out the restoration, using traditional, time-honored skills.

Pre-project planning

Curahuara's isolation necessitated thorough planning before realization of the project. In the early 1980s the IBC, which is charged with cultural patrimony care in Bolivia, began to survey the site. It conducted an inventory of the church's paintings and con-

FIGURE 3. Exterior view of the church at Curahuara de Carangas.

tents, as part of the Bolivian Cultural Patrimony Inventory Project, to be included in the country's national register. The document that grew out of this project strongly recommended emergency conservation work as it appeared portions of the structure were in danger of collapse, and the roof over the baptistry leaked seriously during the rainy season.

The institute sought funding from the West German government through UNESCO/PNUD (Projecto Naciones Unidas de Desarrollo) for this three-phase project. Economic and technical constraints necessitated extension of the project over a period of five years. The economic constraints derived from limited available yearly funding. The technical constraints were associated with limits on the institute's art conservation staff, the availability of supplies, the complex logistics of transporting materials and staff to the remote site, and the coordination of work with the Curahuara native community.

Timing of each phase of the project had to coincide with the spring and fall dry seasons. The site's only access road is unpaved and is virtually impassable during the rains. Most construction materials had to be brought to the site. The community of Curahuara is adjacent to a small army base. The community is without electricity or running water. IBC staff decided to seek the assistance of the army camp—which shares two walls in common with the churchyard—in the project. The only communications links between Curahuara and the rest of Bolivia are through the base radio. The military also assisted with labor, transport of materials, and other logistics.

Mud brick fabrication

The making of mud brick in the Bolivian altiplano can only be accomplished during short periods in the spring and fall when drying conditions are optimum. It can be made neither in the bitter temperatures of winter—it will freeze and crack—nor during the rainy summer season—it will not dry. The technology of making new bricks to replace damaged ones was provided by local craftsmen, expert in this type of construction, but always with an architect's oversight. Men are primarily responsible for making the brick, though women will assist by gathering straw.

Testing for different textural fractions of the adobe yielded a stratigraphy of four layers. Small pebbles settled to the bottom of the test vial and were covered by a layer of clay. A stratum of sand overlaid the clay, while fragments of straw floated to the top of the water used to fractionalize the adobe sample. These results indicate the adobe was fabricated from at least two types of local soil and amounts of local grasses. Further analysis with standard microscopy could reveal more about the material components of the adobe.

Phases of Treatment

Each of the project's three phases lasted about two or three months. Each phase was designed to be capable of being completed in the projected time frame and also to be complete unto itself, although complementary to the other phases.

Phase I. Phase I began in 1984 and consisted of clearing the churchyard of debris, rebuilding the churchyard walls, conducting archaeological excavations, performing soil tests, and conserving wall murals. Also, emergency reconstruction was conducted on the principal interior arch between the sanctuary and nave; it had collapsed the previous year, as the IBC survey indicated it might, endangering the structural integrity of the roof. (see Figure 4).

Clearing the churchyard was an interesting communal event. Citizens from adjoining communities and military personnel worked together to remove trash and rubble and to reconstruct the churchyard walls. Archaeological excavation at the site was organized through the Bolivian Institute of Culture. Uncovered in one of the test pits was an pre-Columbian tomb with textiles and intact skeletal remains. Other, smaller tombs also were found. The excavations also assisted in determining soil stratigraphy, soil composition, and potential sites for new drainage pipes to carry runoff away from the church.

Interior consolidation of wall murals by IBC staff was planned with the solution of two different technical problems in mind. First, to solve the problem of adhesion between the adobe and plaster layers, polyvinyl alcohol was injected with syringes into the voids behind the plaster lime wash. Then, a 5% solution of Acryloid B-72 in toluene was brushed onto the murals to consolidate the paint layer. IBC staff were careful to wear masks to protect them from solvent exposure. It had been suggested that epoxy

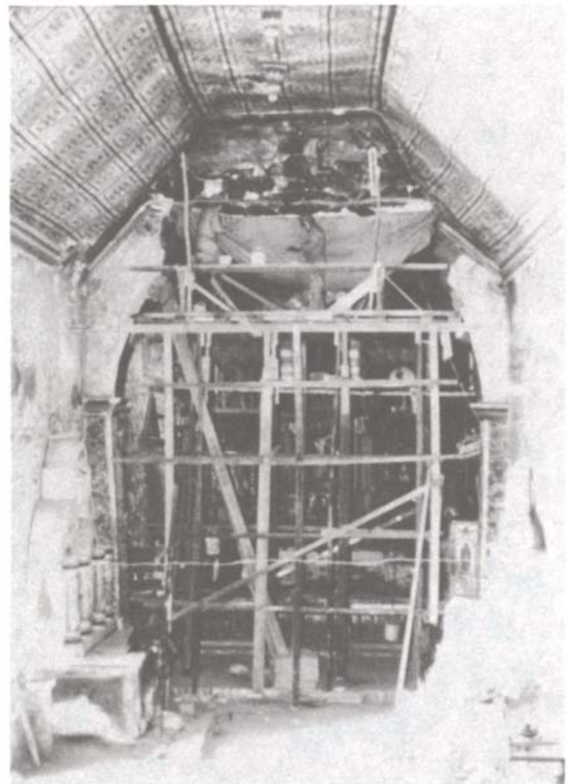


FIGURE 4. Reconstructing the presbytery arch.

might be used to solve the problem of readhering the plaster to the adobe. This idea was discarded because epoxy's high viscosity and quicker drying time made it less suitable than the thinner polyvinyl alcohol, which permitted multiple applications and therefore created better adhesion.

After the surface of the murals dried, IBC staff cleaned them with gum erasers. Owing to constraints of time and resources, no inpainting was performed on the murals, although backgrounds were toned to match surrounding areas.

Reconstructing the presbytery arch formed the most challenging aspect of this phase. Wooden scaffolding and braces were erected to prevent further collapse. An iron rod was inserted between the wall supports to strengthen the walls' integrity and to form a skeleton for the arch, which was rebuilt with mud bricks. The arch was whitewashed and toned to match the surrounding decorative scheme. Because of the site's extensive structural needs, inpainting was confined only to areas in which it was required to reconstruct visual unity. Many areas were stabilized but not inpainted.

Phase II . This portion of the project took place in 1985, when the church exterior was cleaned and resurfaced and the roof replaced. The exterior was swept clean with brooms of local manufacture, then resurfaced with adobe mortar and painted with lime wash. Replacement of the roof involved approximately 100 laborers from the ten neighboring communities, who were employed to make mud brick and cut reeds and grass. Soldiers assisted with the transportation of materials from the lowlands: bamboo and trees of substantial girth do not live in the altiplano, and thus needed to be transported to the site.

Once again, traditional native construction technologies were used. Reeds were gathered by women and children, and heavy construction was done by male craftsmen. Craftsmen prepared new bricks in wooden molds, let them dry and installed them. Bricks were joined with mud mortar and later whitewashed with lime. A few modern materials were used; they complemented and were compatible with the original, locally available and financially feasible ones. For example, wire mesh reinforced the roofing thatch, and zinc flashing directed rain runoff.

Although the roof had been renewed periodically over the centuries—mostly on an emergency basis—its degraded condition mandated it be replaced entirely, including some deteriorated beams, one section at a time. Wooden support beams were set into adobe at the top of the walls. Next, bamboo reeds were secured to the beams; the wire mesh was applied to the reeds as a base upon which to attach the thatch. Interior and exterior views of the completed roof indicated it was identical in appearance to the original.

Phase III. The major effort during this phase of the project, in 1987, was the cleaning and stabilization of the free-standing bell tower, located in one corner of the churchyard adjacent to the army camp. Again traditional technology was used to stabilize mud brick with mud mortar and lime whitewash.

Drainage pipes were installed in the churchyard and drainage stones excavated at the exterior base of the church walls. These flat stones probably date to the construction of the building and were designed as part of the water runoff system.

Future site preservation agenda

The project ended with completion of the 1987 restoration season, although more work remains to be done, such as restoration of the main altar. The local communities, whose ancestors built the church, were again charged with the church's upkeep. Religious ceremonies continue to be performed in the church on a limited basis; Curahuara lacks a permanent priest.

Visiting IBC staff continue regular monitoring of the site. Any earthen architectural artifact requires careful attention and constant care. Recently one large buttress had to be renewed. However, two major problems threaten preservation of the church. As the native population declines, the time-honored system of communities providing its upkeep is endangered. Also, the potential rerouting of the Chile-Bolivia highway would effectively cut Curahuara off from outside traffic which currently passes the town on its way to the Chilean border. Moving the highway would also necessitate moving the military base, which the town depends on in many ways for its survival.

On the hopeful side, the project at Curahuara has served as a role model for other remote colonial adobe sites at Carabuco and Caquiaviri, where similar problems have been encountered, similar treatment methods have been employed, and the strategy of integrating local communities into restoration projects have been used with equal success.

Analytical work on cross-sections of paint layers and identification of materials from the Curahuara site continues. Analysis of the cross-sections will be forthcoming.

Conclusion

The church at Curahuara in the Bolivian altiplano is famed for its early colonial murals, the most complete grouping from this period in all South America. Throughout the centuries native descendants of the builders were charged with its care and preservation, but the church has degraded much in recent decades owing to the economic problems in the region. A recent site survey by the Bolivian Institute of Culture identified needs and proposed international assistance, which was forthcoming through UNESCO. In a three-phase project, IBC staff, local craftsmen, and military workers cleared the site, replaced the roof, cleaned and stabilized the murals, replaced adobe, and whitewashed the walls of the church and free-standing belltower. The project was unique in that it integrated IBC professionals, local craftsmen, and the military. The church has been and continues to be a source of historical importance and community pride at this remote site.

ABSTRACT

The southwestern region (Southwest) of the United States preserves an important patrimony of architectural finishes composed of and executed on earth-based renderings. These finishes, plain renderings (e.g. "plaster") and mural paintings, have been employed extensively by the prehistoric and historic Pueblo peoples (Native Americans) of the Southwest on their complex domestic and ceremonial architecture. This paper summarizes three areas of research on Pueblo finishes, concentrating on the Pueblo III period (A.D. 1100-1300):

1. Laboratory analyses. Samples of Pueblo renderings were analyzed with methods developed by the National Bureau of Standards. Much of the resulting data was unexpected.

2. Simulation of murals to test detachment methods. Simulated Pueblo murals provided models for testing several techniques for detachment of finishes from threatened sites.

3. Pilot conservation treatments. The objective of the pilot conservation treatments was to develop methods for stabilization of finishes on site in the Southwest. Minimally intrusive methods were stressed. A holistic approach to conservation is recommended.

KEYWORDS

Mural painting conservation, detachment of mural paintings, conservation of earthen renderings, analyses of adobe.

ANALYSES AND CONSERVATION OF PUEBLO ARCHITECTURAL FINISHES IN THE AMERICAN SOUTHWEST

Constance S. Silver
949 West End Ave.
New York, NY 10025
USA

Pueblo Finishes: An Overview

The American Southwest includes the states of Arizona, Colorado, New Mexico, and Utah. The region is characterized by deserts and semi-arid steppes traversed by a few rivers and by mountain ranges that support pine forests. Winters are cold and relatively dry. Summers are hot and dry, but heavy rain storms are common. The Southwest lacks many resources. Over the centuries, intensive dry farming and river irrigation at lower altitudes have sustained native peoples.

By 1100 A.D., the prehistoric peoples of the Southwest had developed a complex architecture of earth, cut stone and mud mortar, timber roofing, and architectural finishes composed of earthen renderings. Prehistoric Pueblo culture and architecture culminated in the Pueblo III period (A.D. 1100-1300), exemplified by the remarkable "cliff dwellings," highly developed settlements of domestic structures, four-storey towers, plazas, and subterranean ceremonial kivas, constructed within natural rock shelters (See figs. 1, 2). Both ceremonial and non-ceremonial structures were finished with refined renderings composed of several superimposed strata.

Pueblo kivas were often painted with ritually significant mural paintings. Briefly described, a preparatory coarse-textured rendering (e.g. "brown coat") was applied to the masonry walls of the kiva, followed by a fine-textured finish rendering. The finish rendering was embellished with a variety of techniques, as seen in the Pueblo III kiva of site LA 17360, New Mexico (See figs. 3, 4). Color fields of white and red paint were applied as horizontal bands. Designs were then painted by brush or incised into the plaster. Painted impressions were also made of handprints. New murals were executed by superimposition of new finish rendering onto the existing mural painting, followed by painting.

Kiva murals, their technique of execution and cultural content, were studied extensively by Watson Smith in the 1930s and 1940s.(1) Indeed, Smith's research was so comprehensive that few subsequent anthropological and technical studies were undertaken until those carried out by the author and other researchers over the last decade.(2) This research has indicated that Pueblo builders also developed and employed a formal scheme of architectural embellishment. Although less complex than kiva murals, these finishes include simple renderings, white washes, colored washes (pink and red), bichrome designs (See fig. 5), and painted designs.

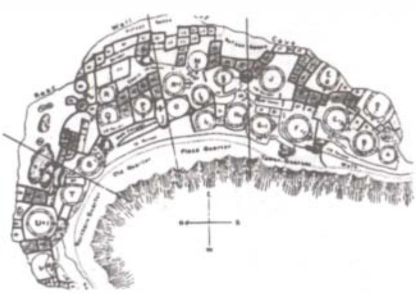
Smith made several important observations about Pueblo finishes. His analyses revealed the Pueblo palette to be a judicious use and mixture of naturally occurring pigments. Although no formal analyses were made of paint media, Smith's ethnographic models suggested many possible sources. Smith also observed that Pueblo architectural finishes and mortar are two different components of a wall; they differ in form, function and physical composition. Mortar is a structural component of masonry. For example, at the site of Awatovi, Arizona, mortar was composed primarily of "clay or adobe," with varying admixtures of sand. It was compact, cohesive, but coarse-textured, with a gray or green tinge. By contrast, the finishes applied to walls, especially in kivas, were composed of a fine-textured, reddish-brown rendering. Smith also observed that this rendering had excellent properties. It cracked and shrank only slightly after drying. While it was not totally waterproof, it did withstand considerable dampness and even some direct rain. However, it also had the capacity to be re-plasticized repeatedly by the addition of water. These observations by Smith pointed to a highly developed and selective use of earthen materials in architecture by Pueblo peoples. Further, the capacity of Pueblo renderings to be re-plasticized suggested minimally intrusive techniques for conservation of finishes on site, as will be described in a following section of this paper.

Pueblo Finishes: Analyses of Component Materials

In 1987, the author examined samples of Pueblo renderings and mural paintings with analytical methods established by the National Bureau of Standards to characterize adobe.(3) These analyses had three objectives: first, to expand understanding of prehistoric Pueblo technologies, specifically to ascertain if Pueblo finishes differ from structural adobe; second, to determine if Pueblo finishes have special properties which have contributed to their longevity and which might be used in conservation treatments; and third, to ensure that simulated murals used for testing detachment methods provided reasonably appropriate models.

The National Bureau of Standards recommends seven analytical methods for structural adobe. Samples were analyzed from sites in Arizona: Escalante Ruin, a prehistoric Pueblo site; Tumacacori, an eighteenth-century Spanish colonial church; soil adjacent to Tumacacori; and Fort Bowie, a nineteenth-century Fort. In 1987, the author analyzed renderings from the following sites: 1. Lowry Ruin, Colorado, mural painting from Kiva B (c. 1100 A.D.); 2. River House Ruin, Colorado, mural from a kiva (c. 1200 A.D.); 3. comparative sample of raw earth from a possible "adobe soil quarry," Mesa Verde National Park, Colorado; 4. comparative sample of a Pre-Columbian painted rendering from Cardal Lur, Peru; 5. comparative sample of nineteenth-century earthen rendering from Mission Santa Cruz, California; and 6. comparative sample of commercial raw adobe from Santa Fe, New Mexico. Due to the small size of the samples, two analyses could not be carried out, identification of soluble salts and evaluation of liquid and plastic limits. Analysis of organic media, omitted by the National Bureau of Standards, was included. The results of the analyses are summarized, including relevant analyses of structural adobe by the National Bureau of Standards.

1. Mesa Verde National Park. Cliff Palace, the largest cliff dwelling in North America.



2. Plan of Cliff Palace (Fewkes)

Analyses of Microfabric

The microfabrics were examined by the following methods: microscopic analyses of cross-sections in reflected light; thin sections in reflected light and polarizing light; and scanning electron microscope (SEM) photographs of cross-sections of rendering and paint.(4)

The Pueblo renderings closely resemble each other, although separated by 160 km and about 100 years. They exhibit a homogenous consistency, in marked contrast to the other samples.

Munsell Color Determinations

The Munsell Soil Color Charts (1975 edition) was used. However, the number of samples was too limited to permit general conclusions about consistency of color.

Determination of pH

A Hach Kit was used.(5) The results are compared to pH analyses of the structural adobes:

National Bureau of Standards Sample	pH	1987 Analyses of Renderings Sample	pH
Escalante Adobe	8.19	Lowry Ruin	6.09 +-.02
Fort Bowie	8.72	River House Ruin	7.66
Tumacacori Adobe	8.12	Cardal Lur	7.21
Tumacacori Soil	8.26	Mesa Verdè "Adobe" Soil	7.69
		Santa Fe Commercial Adobe	8.20

The pH levels of the Pueblo renderings vary from slightly acidic to pH neutral, whereas the structural adobes are all somewhat basic, including the commercial adobe from Santa Fe. However, in this regard it is interesting to note that the sample from the possible "adobe soil quarry," Mesa Verde National Park, conforms to the pH range of the Pueblo renderings.

Determination of Particle Size Distribution

Particle size distribution was analyzed by Dr. Nicholas Coch, Department of Geology, Queens College, with state-of-the-art instrumentation.(6) Dr. Coch observed several unusual characteristics of Pueblo renderings:

> All samples had to be run again because of the continuous presence of aggregates in the coarse fractions of some of the samples. These samples were easily the hardest ones I have ever analyzed because of the very strong cementation between particles by iron oxide and clay. This required additional heavy physical disaggregation plus an adjustment of both the chemical disaggregation and the ultrasonic probe disruption of the sediment samples.

The results are compared to particle size distribution studies of the structural adobes:

Sample	Gravel	Sand	Silt	Clay
National Bureau of Standards Samples				
Escalante Adobe	(not analyzed)			
Fort Bowie Adobe	25	59	9	7
Tumacacori Adobe	5-8	65-80	8-12	8-12
Tumacacori Soil	2	24	26	
1987 Analyses of Renderings				
Lowry Ruin	.00	28.09	58.61	13.30
River House Ruin	.00	19.20	62.03	18.77
Mesa Verde "Adobe" Soil	.08	57.85	25.56	16.51
Santa Fe Commercial Adobe	5.32	41.85	18.27	34.56

The Pueblo renderings are distinctive and anomalous when compared to the other samples. Their particle size distributions are primarily in the silt and clay ranges--although the "clay" range does not automatically confirm the mineralogical presence of true clays.

Mineralogical Composition

X-ray diffraction was used. The Pueblo renderings and samples from the possible "adobe soil quarry," Mesa Verde National Park, tested negatively for the presence of mineralogical clay. These results were so surprising that the samples were tested independently with SEM X-ray analyses (SEM and EDS). Again, the results were negative for the presence of clay. There are two possible explanations. First, the samples may, indeed, contain no clay. Second, and more likely, there is a clay component but it is present in amounts too small to be detected by the X-ray diffraction analyses. That is, in general a mineral phase will not be detected if it comprises less than 10 percent of the total sample. To detect clay, the clay-size category of the particle size distribution should be analyzed separately for the Pueblo renderings.(7)

3. New Mexico, Site LA 17360. View of the kiva and its mural paintings.

Analyses of Organic Media

Histochemical stains were applied to the Pueblo renderings and paint.(8) Positive results for organic media in the paint layers were not unexpected. However, the presence of carbohydrates, lipids and proteins in the rendering from River House Ruin was unexpected:

Sample	Period Acid Schiff (carbohydrates)	Vangiesen Stain (proteins, usually collagen)	Xantho Protein Stain	Sudan Black (lipids)
Lowry Ruin Paint	Positive	Positive	Not Tested	Negative
Lowry Ruin Rendering	Negative	Negative	Negative	Negative
River House Ruin Rendering	Positive	Positive	Positive	Positive

4. Site LA 17360. Detail of the mural paintings.

Simulation of Pueblo Murals to Develop Methods for Detachment

Pueblo mural paintings have been detached by the *strappo* method, which removes only the pigmented layer from the rendering. *Strappo* can be time-consuming in the case of multiple strata, which must be removed individually. Consequently, murals have been lost when they could not be removed in a timely manner from threatened sites. Further, with the *strappo* method the original texture and optical qualities are lost with the destruction of the rendering.

The objective of the experimental program for detachment was to determine if available conservation materials can effect complete removal of rendering and painted strata by the *stacco* method: *stacco* entails detachment of rendering and paint as a unit.

5. Mesa Verde National Park. Spruce Tree House, rendering painted with a bichrome design.

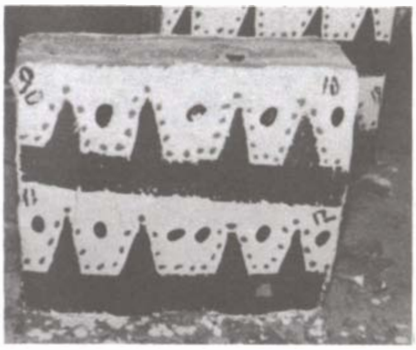
To effect complete removal of a Pueblo mural, the soft, friable and laminated structure of rendering and paint layers must be transformed into a hardened and cohesive unit. Tests on samples indicated that the alkoxysilanes (ethyl silicate), partially polymerized ethyl silicates, and alkyl (alkoxy silanes), provided effective and thorough consolidation with minimal changes in optical qualities. Conservare OH(R) and Conservare H(R) produced the best results. Once consolidated, supportive facings can be adhered to the hardened surface of the mural, preparatory to separation of the rendering from the wall.

Four cement blocks, each measuring 45 cm by 40 cm, were covered with a rendering made from commercially available adobe. The adobe was sifted through a 1/15 cm screen, mixed with water and sand, and applied by hand in several strata, to create a total thickness of about 1.3 cm. Although the consistency of this rendering did not conform to the analyzed prehistoric Pueblo renderings, it did provide an adequate model for test purposes.

Each surface was divided into four sections, to create a total of 32 individual mural paintings of uniform composition and design, each measuring about 18 cm by 20 cm. Documented Pueblo pigments were used. The pigments were mixed with rabbit skin glue to create a workable paint. A kaolin-white color field was applied. A characteristic "dado" design was painted on the white field in iron-oxide red and yellow, and bone black (See fig. 6)

Unexpectedly large quantities of materials were required. About 36 kg of raw adobe earth were needed to create a satisfactory rendering that would cover 1.5 m^2 in a layer about 1.3 cm thick. About 1.36 kg of kaolin and 90 mL of rabbit skin glue were needed for each 1.5 m^2.

Murals 1-6 were left untreated, as controls. Murals 7-18 were consolidated with Conservare OH. Murals 19-32 were consolidated with Conservare H, which contains a hydrophobe. Various combinations of isolating coatings on the painted surfaces, facing fabrics, and adhesives for facing fabrics were tested. Adhesives and isolating materials included: polyvinyl alcohol; rabbit skin glue; Acryloid B 72; BEVA(R); Soluvar Matte(R); and Blair Spray Fix(R). Facing fabrics included: Japanese tissue paper; surgical gauze; crepeline; and monofilament. Each individual mural was treated with a different combination of these materials.



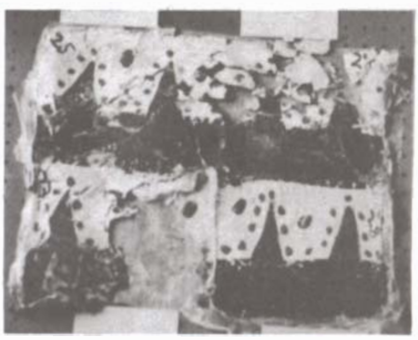
6. Simulated Pueblo mural paintings.

The faced murals were detached by separating the rendering from the block with a thin blade and hammer. The detached murals were adhered to a solid support. The facings were removed with appropriate solvents. The various combinations of materials produced a range of results from excellent (detachment of the mural intact and largely unchanged) to very poor (almost 50 percent loss of rendering and paint). The excellent results for Murals 14 and 28 were particularly interesting because the same isolating layer, Blair Spray Fix, and the same facing adhesive, polyvinyl alcohol, were employed. Conservare OH also increased the resistance of Mural 28 to the water-based polyvinyl alcohol (See fig. 7).

The experimental program indicated that detachment by stacco is possible. However, it has not been tested in the field. Therefore, its performance in the case of very thick, friable and delaminated murals is not clear.

Conservation of Finishes on Site in the Southwest

A series of pilot conservation treatments was carried out in 1981 at Mesa Verde National Park.(9) The objectives of the pilot treatments were to develop methods for the stabilization of deteriorated painted and unpainted Pueblo renderings on site in the Southwest. Mug House Ruin (MV 1229), a Pueblo III site, provided two representative examples: Kiva C, a subterranean circular kiva, and an above-ground wall that is semi-protected by the cliff overhang. Because the pilot treatments were similar, only the treatment of Kiva C is summarized.



7. Simulated Pueblo mural paintings, after detachment.

Kiva C was excavated in 1960, and it has remained exposed. There are about 10 superimposed layers of fine-textured renderings on the rougher preparatory rendering, creating a total thickness of about 2.5 cm. The visible mural painting is a white and red "dado" design.

Between 1960 and 1981, considerable deterioration had occurred. The murals that survived on the walls were very unstable. Several conservation problems were evident: detachment of rendering from wall; delamination between strata; friable rendering; friable rendering and paint; flaking paint; efflorescence of salts; root penetration; burrowing and abrasion by insects and rodents; and surface dirt.

The most serious conservation problem was the instability of the rendering and paint, so severe in some areas that the mural could not be touched without provoking further damage. In considering the rheological behavior of the rendering and paint, it was evident that water would be the most effective material for conservation treatment because it can relax and re-plasticize the brittle and deformed rendering to permit compaction and cohesion of the delaminated strata and their repositioning in plane as a unit on the wall. Water also reactivated the bond between the paint and the rendering. The pilot conservation treatment is summarized:

1. Wet-strength Japanese tissue was attached to the surface of the rendering, both painted and unpainted areas, with water that was applied by brush. The paper acts as a support and ensures that the surface remains protected during treatment. The area was lightly sprayed with water until the rendering had become malleable.

2. A 50:50 mixture of water and isopropyl alcohol was injected as a wetting agent between the rendering and the wall. A 25 percent solids polyvinyl acetate emulsion was injected into areas of detachment between the rendering and the wall, and between the second layer of preparatory rendering and the first layer of finish rendering. The adhesive was not in contact with any of the painted layers (See fig. 8).

3. The treated area was then pressed gently back into plane on the wall. Local pressure was used on the dampened rendering to compact the strata, renewing the cohesive strength and re-establishing continuous contact between paint, rendering and wall. During treatment, the surface of the mural remained generally visible through the Japanese paper, allowing the treatment to be monitored.

4. Simple presses, constructed from plywood and faced with foam rubber, were placed in contact with the treated areas, to maintain drying under pressure for 48 hours. The presses were held in place by wedging them with plywood shafts that were weighted at the ground with large rocks (See fig. 9).

5. After drying, the Japanese paper was removed. Some dirt was removed on the paper, but paint and rendering remained unaffected. With the exception of some very unstable flakes, the treated areas had become a cohesive unit secured to the wall.

6. Unstable flakes of paint were adhered with localized applications of Acryloid B 72, about 8 percent in toluene. Repeated applications of acetone removed surface residues; however, changes in optical qualities, primarily a deepening of tone, would be apparent if large areas were treated with resins.

7. A very friable area of rendering was treated with Tegovakon T(R), an alkoxysilane manufactured by Th. Goldschmidt. Conservare H and Conservare OH produce better results, but they were not readily available in the United States in 1981.

8. Efflorescence of salts were initially removed by light brushing with a sable brush. Tenacious salts were treated with a compress of paper pulp infused with a saturated solution of bicarbonate of soda. The compress remained in place for about 5 hours. Compresses of distilled water followed. About 50 percent of the salts were removed, with no damage to the rendering or paint.

8. On-site pilot conservation treatment. Injection of adhesive after facing with Japanese tissue.

9. Rotted roots were removed by standard mechanical methods, such as brushing.

Kiva C was re-examined in 1985. The treated murals had remained stable. This treatment reflects the author's bias in favor of minimally intrusive methods of conservation. Conservation is primarily effected by renewal of the correct rheology of the rendering through judicious use of water. The mural retains its original Native American character and the original optical qualities remain unaltered. Future conservation treatments are not compromised. The treatments are so simple that they can be implemented by any trained conservator. The cost of treatment is low.

9. The treated area drying under pressure.

Two caveats are in order. First polyvinyl acetate emulsion has been used extensively in the conservation of mural paintings. However, adhesives that better retain their chemical stability and permit some transmission of water should be developed. The question of biodeterioration of adhesives when used on site also requires further examination. Second, it must be understood that fragile Pueblo renderings and murals cannot be preserved, regardless of conservation treatment, if they remain subject to adverse environmental conditions. In the case of excavated kivas, conservation treatments must be followed by controlled backfilling. Several excellent methods and materials are now available for backfilling.

Conclusions and Recommendations

Although only a few samples were analyzed, the results suggest a highly refined and very selective technical tradition of Pueblo finishes. The possible absence of clay and the inclusion of organic media are particularly intriguing. Analyses of a similar mural painting tradition from Buddhist Central Asia resulted in precise identification of the sources of organic media.[10] Similar analyses of a large sample of Pueblo renderings might increase understanding of use of the limited resources of the Southwest by prehistoric Pueblo peoples. It might also be possible to incorporate traditional materials into future conservation treatments, thus maintaining consistent and compatible systems throughout a mural painting or rendering.

All detachment methods result in some damage to a mural. Changes in optical qualities occur. The ensemble of mural and architecture is disrupted. Therefore, detachment is always a treatment of last resort. The methods described in this paper for *stacco* provide a possible option for removal of murals from threatened sites.

Additional research is required to develop a specific adhesive adapted to reattachment of Pueblo renderings to walls on site in the Southwest. The acrylic emulsions may be good candidates.[11] In this regard, it should be noted that the adhesive need not be extremely strong to be effective. Indeed, an overly strong adhesive could promote mechanical stress. Rather, properties of ageing, biodeterioration and water transmission are more important considerations.

Following development of a more appropriate adhesive, a holistic approach to conservation should be implemented, controlled backfilling being an integral treatment for kivas.

Materials

BEVA. Developed in the late 1960s by Gustav Berger as an adhesive for relining canvas paintings. The basic composition is:

Elvax Resin Grade 150 (Dupont). . . .	.250 g
Ketone N. Resin (BASF).	.150 g
Cellolyn 21 Resin Hercules.	29 g
A-C 400 Copolymer (Allied Chemical) .	85 g
Paraffin Oil-Free (65 C°Melt Point) .	50 g

BEVA is available from Conservation Materials Ltd., 340 Freeport Blvd., Sparks, Nevada 89431, USA (702 331-0562).

Blair Spray Fix. Trade name of a nitrocellulose-based fixative. It contains nitocellulose resin, methylene chloride, alcohols, acetates, and ketones. It is made by Blair Art Products, Inc., Twinsburg, OH 44087 USA.

Conservare H and Conservare OH. The basic composition is 2-propanone, 2-butanone and tetraethylorthosilicate. Originally manufactured by Wacker-Chemie, Munich, Germany, these consolidants are available in the United States from ProSoCo, Inc., P.O. Box 1578, Kansas City, Kansas 66117 (913 281-2700).

Soluvar Matte. Soluvar and Soluvar Matte are acrylic resin varnishes, produced in the United States by Liquitex, Binney & Smith, Inc., Easton, PA 18005-0431. The principal component is isobutyl methacrylate polymer.

Tegovakon. Th. Goldschmidt, AG, Essen,Germany, has marketed five stone consolidants: Sandstone Consolidant, a two-component product containing ethyl silicate, methyl (triethoxy)silane, ethanol, and hydrochloric acid and water; Tegovakon, similar to Sandstone Consolidant; Tegovakon H, a two-component mixture of "silicon esters" and water-repellent; and Tegovakon GS, a single component similar to Tegovakon H; and Tegovakon V, ethyl silicate.

Notes

1. Watson Smith, Kiva Mural Decorations at Awatovi and Kawaika-A (Cambridge: Harvard University Press, 1952).

2. Constance S. Silver, "Architectural Finishes of the Prehistoric Southwest: A Study of the Cultural Resource and Prospects for its Conservation" (M.S. thesis, Columbia University, 1987). The author gratefully acknowledges the assistance of Professor Norman Weiss, Columbia University, and Watson Smith.

3. P. W. Brown, J. R. Clifton, and C. R. Robbins, Methods for Characterizing Adobe Building Materials (Washington, D.C.: U.S. Government Printing Office, 1978).

4. Lorraine Schnabel, personal communication to the author, September 2, 1987.

5. Dr. David Spidel, Chairman, Department of Geology, Queens College, Queens, New York. Personal communication to the author, September 23, 1987.

6. Dr. Nicholas Coch, Department of Geology, Queens College, Queens, New York. Personal communication to the author, June 29, 1987.

7. X-ray diffraction was carried out by Gregory Cavallo, American Museum of Natural History, New York City (personal communication to the author, July 17, 1987). The results were verified with SEM X-ray diffraction (SEM and EDS) by Dr. Robert Koestler, Metropolitan Museum of Art, New York City (personal communication to the author, September 4, 1987). The author gratefully acknowledges review of these data and suggestions regarding the relationship between quantity of mineral and detection by X-ray diffraction by Richard Coffman and Neville Agnew, Getty Conservation Institute (personal communication to the author, April 9, 1990).

8. McCrone Associates, Inc., personal communication to the author, September 9, 1987.

9. The pilot conservation treatments at Mesa Verde National Park were supported by four institutions. The National Museum Act (Grant FG-107214000) provided financial support. The Museum of New Mexico was the sponsoring institution. The National Park Service made available protected sites. Technical in-kind support and consultation by Paul M. Schwartzbaum were provided by the International Centre for Conservation, Rome (ICCROM). The author was project director.

10. V. J. Birstein, "On the Technology of Central Asian Wall Paintings: The Problems of Binding Media," Studies in Conservation 29, No. 1 (February 1975): 8-19.

11. M. W. Phillips, "Experience in the Use of Acrylic Plaster Adhesive," Case Studies in the Conservation of Stone and Wall Paintings, IIC Bologna Congress, 21-26 September, 1986, 34-37.

ABSTRACT

A methodology for the conservation and restoration of earthen structures is proposed.
This methodology encompasses the study of the physical environment, historic values, the state of the building and the evaluation of the architectural typology and architectural significance. These elements are taken into account in a cyclic approach to balance between the different kinds of values that are important in the definition of the intervention.
In this way the technical problem of conservation of earthen structures is embedded in a global evaluation that is appropriate for the preservation of the monument.

KEYWORDS

Methodology, conservation, earthen architecture, restoration.

MÉTHODOLOGIE DE LA CONSERVATION ET DE LA RESTAURATION DES MONUMENTS EN TERRE.

Koenraad Van Balen
ingénieur architecte
Centre d'étude pour la conservation
du patrimoine architectural et urbain
K.U.Leuven
Kasteel van Arenberg
B-3030 Leuven, Belgium.

Introduction.

La lecture de différentes méthodologies proposées pour la conservation des constructions en terre montre que celles-ci se limitent en général à un point de départ où le problème technique de la conservation des matériaux est abordé (1). Ceci mène en général à des solutions techniques qui perdent de vue le cadre architectural et social, tant pour l'évaluation du problème posé par la conservation que pour les possibles solutions.

Pourtant il y a des personnes qui se sont intéressées à l'étude des traditions culturelles avec le but de pouvoir comprendre la tradition architecturale afin de maintenir la main-d'oeuvre, la connaissance du savoir-faire. Ceci peut aussi être utile au conservateur pour la compréhension de l'architecture dans laquelle il intervient ainsi que pour la sauvegarde de la tradition de l'entretien. Ce dernier point est reconnu comme étant de très grande importance pour la sauvegarde du patrimoine en terre (2). Seulement il ne semble pas encore incorporé dans les politiques de sauvegarde, à part que en termes généraux. L'étude des techniques d'entretien et leurs applicabilités dans la conservation semble par contre négligée. Pour un grand nombre de conservateurs ces techniques sont beaucoup trop vigoureuses, bien qu'appliquées pendant des dizaines d'années. Hélas il faut dire que l'efficacité de ces techniques diminue fortement quand les intervalles des travaux deviennent si importants qu'on ne se souvient plus du dernier entretien.

L'intervention doit clairement se distinguer des éléments originaux, comme il est mentionné à juste titre, conformément à la Charte de Venice, dans les différents colloques qui ont précédé celui-ci (3). Mais dans le cas des objets architecturaux ce type d'intervention ne peut satisfaire que quand on tient compte de la dimension architecturale. Pour cette raison nous proposons une lecture et une analyse plus approfondies de la dimension architecturale avant de définir le type d'intervention.

Ce dilemme que pose la conservation du patrimoine architectural - préférence pour l'objet archéologique ou pour le chef-d'oeuvre architectural - se pose par exemple clairement dans l'ancienne ville de Buda.

Il me semble donc qu'il faut ajouter à la proposition faite à Ankara (1980): "... la préservation de l'intégrité de l'architecture en terre comme un tout qui comprend les concepts et techniques traditionnelles qui étaient utilisés à l'origine et continuent à être utilisés aujourd'hui ..." la dimension architecturale.

Pour pouvoir maîtriser ces différentes "dimensions" une approche est proposée et commentée par la suite.

Une méthodologie.

L'intégration de problèmes techniques dans un contexte plus vaste de conservation a été étudiée pour des problèmes de consolidation structurelle (4) et des problèmes analogues d'évaluation de risques dans la protection du patrimoine contre les incendies et d'autres risques naturels (5). Il nous a paru utile d'élaborer une approche similaire pour cette conférence.

Le point de départ de cette méthodologie est que chaque problème technique se trouve dans un vaste contexte qu'il faut analyser profondément. Pour cela une approche pas à pas est proposée qui distingue les phases suivantes: L'ANALYSE; LE DIAGNOSTIC, LA THERAPIE et LE CONTROLE.
Poursuivons ces différentes phases afin d'éclaircir nos idées.

NOTES.

1 par exemple les méthodologies présentées lors du premier cours pilote sur la préservation du patrimoine architectural en terre, Grenoble, du 28/10 au 4/11/1989.

2 colloque précédent sur la conservation des constructions en terre en Iran (1972, 1976).

3 New Mexico (1977), Rome (1987)

4 Lemaire R., Van Balen K. (Editors), Stable-Unstable,

Structural consolidation of ancient buildings, Leuven University Press en M&L, 1988, Leuven;

Van Balen K., "Stabiliteitsherstel in monumentenzorg (Structural consolidation in monument conservation.)", in Monumenten en Landschappen, jg.5, nr.2, 1986, Brussel;

Van Balen K., "Benadering en verantwoordelijkheden bij stabiliteitsherstel (Approche et responsabilités dans la consolidation structurelle)" (conférence lors de la journée d'étude: Monument en stabiliteit (Monument et stabilité); Gent, België.

5 Van Balen K., De Witte E., Buelens R., "De beveiliging van kerken en hun kunstbezit (La protection d'églises et leurs biens meubles)" in Monumenten en Landschappen, jg.5, nr.4, 1986, Brussel

Van Balen K., "L'influence des catastrophes -les incendies- sur l'évolution des bâtiments en pan de bois en Flandre", (conférence au Cours intensif européen sur la protection et la conservation du patrimoine culturel dans les zones à risques sismiques; deuxième cours; Ravello, Italie. *Centre Européen de Ravello en collaboration avec l'Instituto di Formazione del Mesogiorno (FORMEZ)* décembre 1987).

6 voir les théories de Norberg-Schulz.

1. L'ANALYSE.

Un monument historique doit être analysé dans ses différentes dimensions. Il s'agit d'un objet architectural qui reflète une histoire et donc l'analyse historique doit être étudiée. Il s'agit d'un conglomérat de matériaux et donc le comportement de ces matériaux doit être connu. L'architecture nous dévoile aussi une typologie de construction qui ressort de l'histoire de l'architecture et est la réponse envers les différentes restrictions comme le climat, la présence de matières premières, une technologie acquise dans la période de construction et des différentes interventions ultérieures.

L'architecture elle-même est porteuse d'une signification (6), elle est un "symbole" qui doit être compris dans le contexte de la société qui l'a créé, mais elle devient, comme monument historique, un symbole pour notre société d'aujourd'hui.

La phase de l'analyse envisage donc d'effiler ces différentes dimensions afin de pouvoir les estimer et les confronter dans le diagnostic où les grandes lignes de l'intervention doivent être définies.

L'analyse tiendra, entre autre, compte des pas suivants:

a. l'étude de l'environnement dans lequel se trouve l'objet de l'étude, la situation géographique, le climat, le microclimat (urbanistique), la situation dans un réseau urbain, la disponibilité de matières premières, la technologie acquise par la société.

b. l'étude historique du bâtiment basé sur des sources écrites, iconographiques mais aussi des témoins dans la construction même. Cette étude nécessite donc un relevé précis et détaillé du bâtiment.

c. l'étude des matériaux: leur composition originale, l'origine des matières premières employées, leur état de conservation, l'emplacement mutuel, les dégradations qui témoignent de leur incompatibilité (fissures, dégradation plus accentuée dans la zone de contact,...), les caractéristiques physiques et structurels (porométrie, isothermies, ...) des matériaux. Dans le cas des constructions en terre la connaissance de la structure interne du matériau ainsi que les caractéristiques des terres employées pour la fabrication est de grande importance.

d. le comportement mécanique des constructions portantes en terre doit être étudié en tenant compte du système global de la structure et pas seulement des matériaux isolés. Par exemple le comportement d'une paroi en terre renforcée de pannes de bois lors d'un tremblement de terre, ne peut s'expliquer que par la compréhension de l'interaction des différents matériaux.

Les éléments cités ci-dessus semblent assez évidents et font l'objet de la plupart des études préalables, mais nous voulons insister ici que cette approche ne peut satisfaire que si les éléments suivants sont aussi inclus:

e. l'architecture reflète aussi une typologie de construction qui à son tour reflète la connaissance du savoir-faire d'une société à une certaine période. Ceci est déja en soi une dimension intéressante qui vaut l'étude. Certaines de ces typologies sont la cumulation de la connaissance acquise pendant des siècles, des réponses aux restrictions posées par l'environnement et les dégradations qui en suivent. La protection des parois en terre par des grands toits en surplomb dans les régions pluvieuses en est un exemple. La protection des parois en terre par des enduits, qui sont souvent renouvelés pendant les travaux d'entretien, en est un autre.

f. typologie et matériau sont liés entre eux dans la conception initiale du bâtiment et donc dans une approche de conservation. Le conservateur approchera donc avec beaucoup de retenue le bâtiment en respectant la typologie.

Dans différentes régions du monde, souvent les pays en voie de développement, la technologie ancienne a été conservée et on trouve aisément la main-d'oeuvre pour entretenir ces constructions de la même manière que cela a été fait pendant longtemps. La sauvegarde de la technologie, dans ce cas, est possible par la poursuite de la tradition d'entretien.

Dans beaucoup de pays -dits civilisés- cette main-d'oeuvre n'est plus disponible et on a perdu la notion importante de l'entretien régulier. Le problème de la conservation des bâtiments devient alors différent: la sauvegarde de la technologie ne peut alors qu'être garantie par la conservation minutieuse de ses témoins dans des circonstances pénibles créées par le manque d'entretien!

La conservation d'un monument historique nécessite souvent la mise en valeur de la signification dont il est porteur. Cette dimension doit être étudiée afin de pouvoir décider comment se fera l'intervention. Peut-être faudra-t-il une intervention architecturale afin de rendre plus lisible aujourd'hui la signification dont il s'agit.

2. LE DIAGNOSTIC.

Le diagnostic est en effet la confrontation et la synthèse des résultats de l'analyse. Il faudra résoudre différents dilemmes. Je vous en présente quelques-uns.

a. faut-il consolider une ruine de murailles en adobe sans restaurer ces éléments typologiques qui ont été conçus, mais qui n'existent plus, pour la protection des parties supérieures des murs (voir par exemple les surplombs des toitures ou les enduits)?

b. doit-on réemployer comme élément structurel un mur en adobe qui apparemment est lézardé par la perte de cohésion du matériau même et par des fissurations dues à des tassements différentiels? La valeur historique de ce mur sera appréciée différemment s'il porte des traces uniques pour l'histoire ou s'il peut être refait à neuf sans changer vraiment la valeur historique du bâtiment.

c. dépendant de la valeur unique de l'élément sur lequel il faut intervenir, une technique de consolidation et de conservation peut être exécutée pour autant que cette technique offre assez de garantie. Par contre si la valeur monumentale de cet élément architectural ressort de son aspect global cet élément pourrait être refait avec des techniques traditionnelles, même améliorées.

d. beaucoup de constructions en terre ont pu survivre tout au long des décennies, des centenaires par l'entretien qu'elles ont subi régulièrement. Cet entretien de nos jours est souvent négligé et beaucoup de ces bâtiments fragiles en terre sont dans des situations déplorables. La restauration devient alors un travail d'entretien accumulé et ajourné qui devient alors plus radical que la poursuite de travaux d'entretien normaux aurait causé. Ceci peut clairement être illustré à Quito, où la vulnérabilité du patrimoine est accrue par manque d'entretien après les tremblements de terre.

e. la perte de la main d'oeuvre spécialisée et du savoir-faire traditionnel est une hypothèque sur la poursuite des travaux d'entretien tellement nécessaire. Ne faut-il donc pas d'abord parler de la conservation de la main-d'oeuvre et du savoir-faire avant d'aborder le problème de la conservation des bâtiments mêmes?

En résolvant les dilemmes il faudra définir les objectifs précis de l'intervention. Ceci aussi bien au niveau architectural qu'au niveau technique : quelles sont les exigences auxquelles les interventions doivent satisfaire pour garantir une sécurité suffisante pour la protection de l'unicité de l'objet et de la sécurité acceptable pour la société. Ces objectifs s'expriment en termes précis comme par exemple une résistance mécanique de X MPa, une progression de déformation limitée,...

3. LA THERAPIE ET LE CONTROLE.

Dans cette phase seront définis les travaux qui doivent être exécutés. Ils seront décrits et exécutés tenant compte des objectifs définis par le diagnostic. Nous lions directement cette phase au contrôle qui est le "feed-back" vers les phases précédentes.

7 par exemple les expériences à Pueblo Benito avec des constructions en terre; T. Rutenbech, Monitoring structural movements in historic stone masonry buildings in Preprint of the proceedings of the International Technical Conference on Structural Conservation of Stone Masonry, Athens, Greece, October - November 1989.

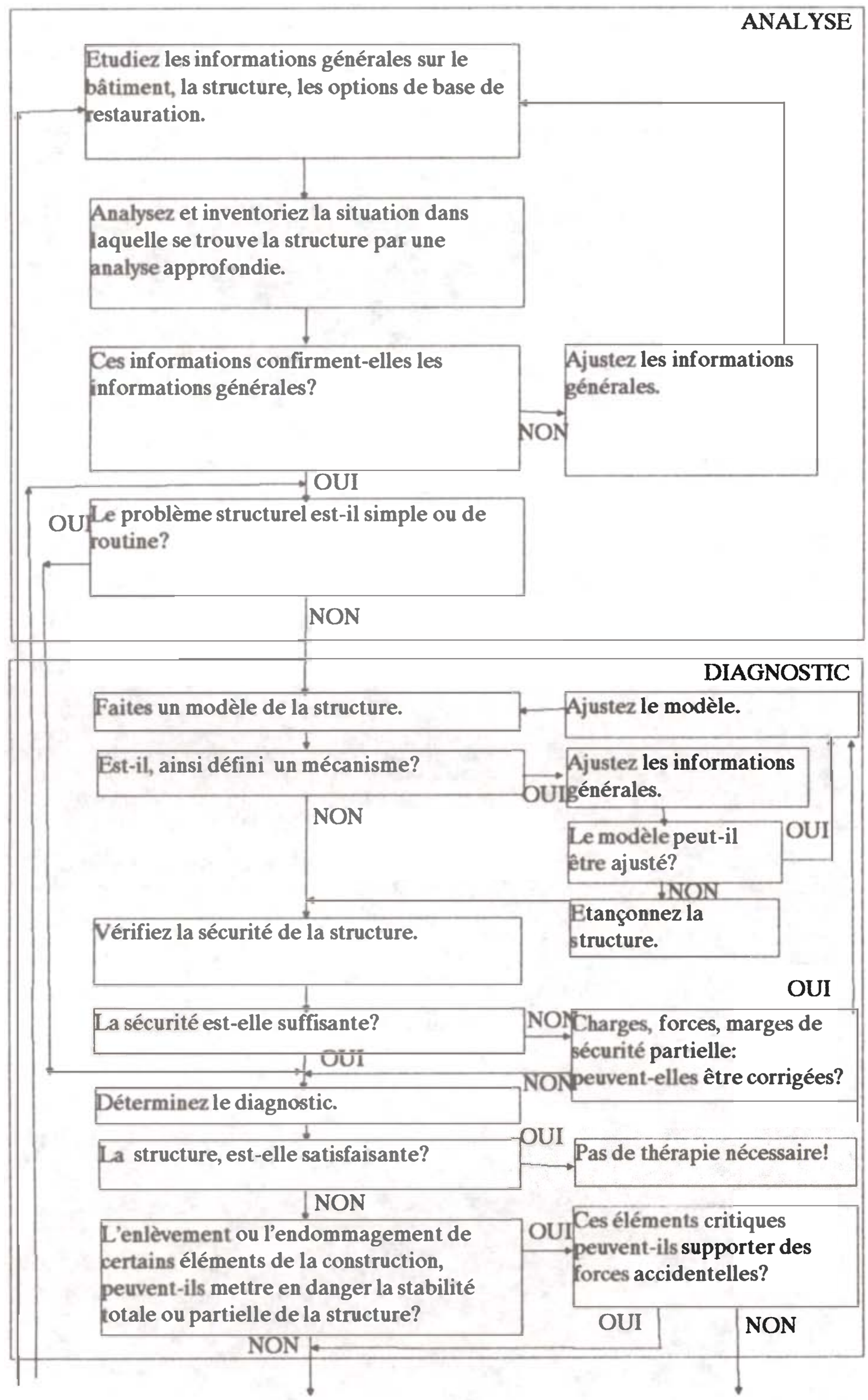
Le contrôle permet en cours d'exécution d'évaluer la thérapie. Les critères d'évaluation sont définis par le diagnostic mais il faut aussi tenir compte de l'incertitude inhérente liée à l'analyse. On constate par exemple lors de l'intervention que les préalables de l'analyse ne sont pas confirmés, ou pire encore, contredits. Il faut alors retourner à la phase de l'analyse afin de revoir quelles sont les implications des nouvelles données sur les décisions prises. Ainsi la méthodologie se présente comme un parcours avec recouplages, chaque nouvelle donnée sera relatée aux valeurs ressortant de l'analyse.

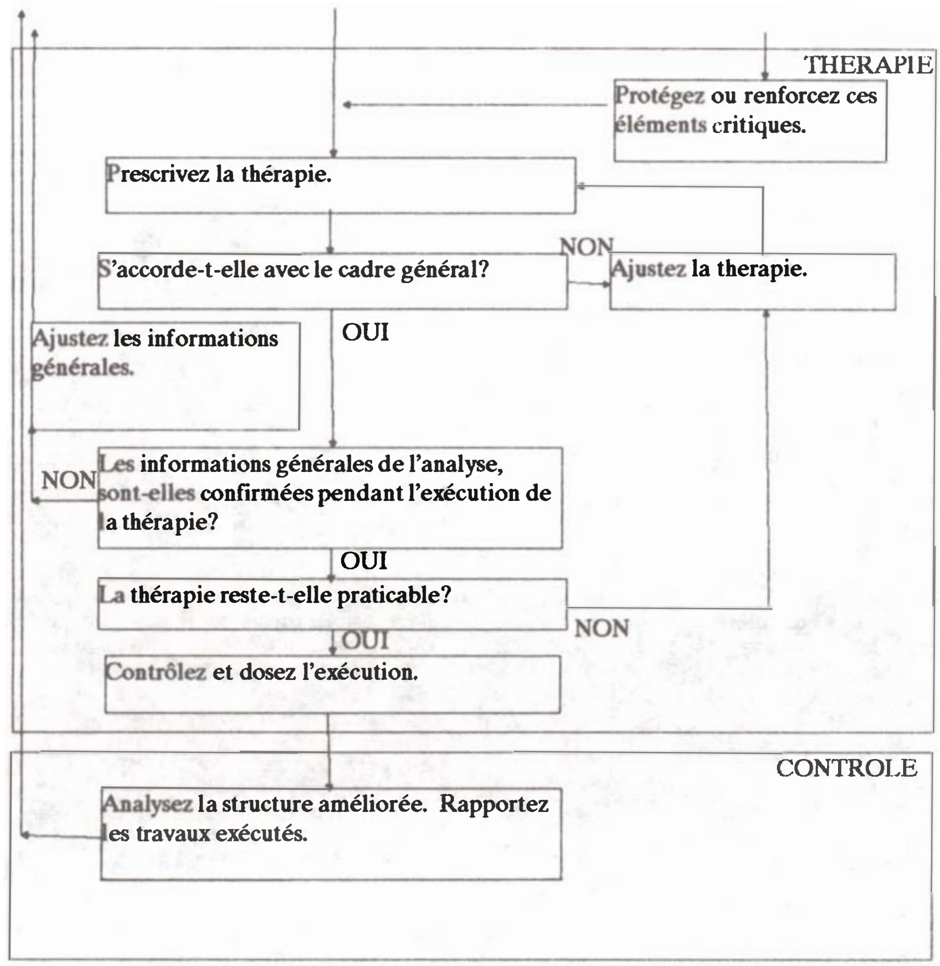
Cette procédure nous donne aussi la possibilité de limiter les travaux excessifs dus aux incertitudes.
Prenons par exemple un mur porteur qui, suite aux charges qu'il porte, subit une déformation croissante. Cette déformation croissante est une mesure pour le manque de stabilité (7) et des calculs devront donner des indices sur les marges de sécurité, qui à leur tour définiront les caractéristiques à donner à la maçonnerie pour qu'un niveau de sécurité acceptable soit atteint. Ces caractéristiques seront comparées aux prestations des techniques qui peuvent être employées et on choisira une méthode qui interviendra le moins possible. Nous savons que dans la méthode de calcul beaucoup de facteurs d'incertitude sont compris et nous devrons essayer de les éliminer le plus possible. Ceci peut se faire par une amélioration de la connaissance du comportement des matériaux ainsi que par l'emploi d'un modèle plus approprié au problème à résoudre. Si pour des raisons de sauvegarde de l'authenticité, une intervention minimale est proposée, un système de contrôle de déformation peut nous aider à évaluer l'effet de l'intervention. Une première intervention peut alors être exécutée et évaluée avec le système de "surveillance". Si ce système de contrôle montre que l'intervention est satisfaisante, même si le calcul avec toutes ses marges d'incertitude n'aurait pas pu le démontrer, une garantie est offerte et l'intervention est minimalisée. Si par contre le système de contrôle ne nous donne pas satisfaction sur les travaux exécutés, parce que par exemple la croissance des déformations n'est pas satisfaisante, une seconde intervention peut être proposée. Ainsi une intervention en cascade peut être exécutée avec chaque fois des étapes minimales qui évitent chaque exagération.

Cette approche que nous avons employée pour l'église de Notre Dame à Ninove en Belgique, montre qu'il est possible d'éviter des interventions qui ressortent de l'incertitude de notre connaissance du comportement des matériaux et du manque d'exactitude des modèles de calcul.

Il s'agit donc de définir, pour chaque type de problème qui se pose dans le bâtiment, les paramètres qui reflètent au mieux l'efficacité de l'intervention. De plus si ce paramètre peut être mesuré avec des techniques non destructives, un système optimal de surveillance peut être établi.

Le schéma des différentes étapes pour résoudre de cette manière un problème de stabilité peut être résumé par le graphique suivant. Pour des problèmes avec les matériaux, des schémas analogues peuvent être élaborés.


ANALYSE
Etudiez les informations générales sur le bâtiment, la structure, les options de base de restauration.
Analysez et inventoriez la situation dans laquelle se trouve la structure par une analyse approfondie.
Ces informations confirment-elles les informations générales?
NON
Ajustez les informations générales.
OUI
OUI
Le problème structurel est-il simple ou de routine?
NON
DIAGNOSTIC
Faites un modèle de la structure.
Ajustez le modèle.
Est-il, ainsi défini un mécanisme?
OUI
Ajustez les informations générales.
NON
Le modèle peut-il être ajusté?
OUI
NON
Etançonnez la structure.
Vérifiez la sécurité de la structure.
OUI
La sécurité est-elle suffisante?
NON
Charges, forces, marges de sécurité partielle: peuvent-elles être corrigées?
OUI
NON
Déterminez le diagnostic.
La structure, est-elle satisfaisante?
OUI
Pas de thérapie nécessaire!
NON
L'enlèvement ou l'endommagement de certains éléments de la construction, peuvent-ils mettre en danger la stabilité totale ou partielle de la structure?
OUI
Ces éléments critiques peuvent-ils supporter des forces accidentelles?
OUI
NON
NON



Conclusion.

La conservation des monuments en terre n'est pas seulement un problème technique qui a comme but de conserver ou restaurer au mieux le matériau.

L'approche proposée veut mettre en évidence l'importance des différentes dimensions de la conservation architecturale qui toutes doivent être prises en considération quand des décisions sur l'intervention doivent être prises.

L'évaluation des valeurs historiques ainsi que l'évaluation des problèmes techniques sont déjà aujourd'hui le sujet de beaucoup d'études préalables aux interventions.

La connaissance et, surtout, l'interprétation à l'égard de la conservation des typologies de construction et la conservation des méthodes d'entretien ainsi que de la main-d'oeuvre sont souvent négligées.

L'étude de ces typologies nous apprend beaucoup sur la durabilité des techniques - y compris les détails architecturaux - suite à une expérience beaucoup plus longue qu' avec les produits modernes. Elle nous aidera à intervenir plus scrupuleusement et d'envisager des solutions architecturales appropriées pour des problèmes même techniques.

CONSTRUCCIONES DE TIERRA, EN EL PERU DE HOY

Julio Vargas Neumann* y Juan Bariola Bernales
Pontificia Universidad Católica del Perú
Departamento de Ingeniería
Apartado 1761, Lima
PERU

ABSTRACT

Within the social framework of Peruvian reality, the importance of housing built with mud and other traditional materials in the region as well as the need of using improved technologies in seismic and rainy areas is presented. A description is contained herein of characteristics, advantages and disadvantages of earthen buildings as well as technical recommendations which have been developed after extensive research programmes and subsequently implemented over the last 15 years in low-cost housing in seismic areas. Recommendations include construction with mud, rammed earth and quincha (bahareque), as well as mud plasters and painting. Many of these recommendations have been included in the Seismic Peruvian Code.

KEYWORDS

Construcción Sismo-Resistente, adobe, tapial, quincha (bahareque), recomendaciones.

KEYWORDS

Seismic-resistant construction, adobe, rammed earth, wattle and daub, quincha, recommendations.

En los últimos 25 años, en el Perú se ha producido un abandono de atención al interior del país, especialmente en la Sierra, y un proceso de migración escalonada del campo a la ciudad.

Como resultado de este proceso, la velocidad de incremento poblacional en las principales ciudades de la Costa, es mucho mayor que la de crear soluciones habitacionales. El déficit anual es de 100,000 unidades. Tugurización y asentamientos urbano-marginales, son notorios en dichas ciudades. Procesos de invasión de terrenos privados, fiscales y públicos, han ido presentándose en forma creciente.

Los precios de la construcción aumentaron a un ritmo mucho mayor que el poder adquisitivo. La obra que construye el Estado, no puede ser adquirida por la población.

Sin embargo, la necesidad e inseguridad de los sectores marginales, los conduce a construir con mucho esfuerzo, utilizando sistemas informales de autogestión y autoconstrucción. La pujanza de este sector lo convierte en el constructor del 75 a 80% de la actividad actual.

Es obvio que frente a este panorama hay que desarrollar dos actividades fundamentales: apoyar los procesos informales existentes y difundir soluciones de muy bajo costo.

No es fácil regresar a soluciones tradicionales. Es necesario conocer la historia, las tradiciones sociales, los problemas poblacionales y sus prioridades, para luego diseñar la solución más adecuada a cada comunidad. Sin lograr una verdadera motivación, es mejor no intervenir apoyando el proceso.

La construccion en tierra, indudablemente de una tasa costo/calidad baja, es una solución en el Perú de hoy.

se estima que el costo de una vivienda rústica de tierra autoconstruida e incluso autogestionada, no sobrepasa de 15 dólares por metro cuadrado y el de una de quincha, 40 dólares. El casco habitable en albañilería de ladrillo, cuesta en la misma región 80 dólares por metro cuadrado y una vivienda terminada de clase media, 200 dólares.

En general, en adelante nos referiremos a las construcciones de adobe, salvo mención expresa.

Las construcciones de tierra, como las de cualquier otro material, tienen una serie de ventajas y desventajas. En función de ellas y de las características ecológicas de cada zona, resulta el mayor o menor uso de este tipo de edificaciones.

Entre las ventajas se puede enumerar las siguientes:

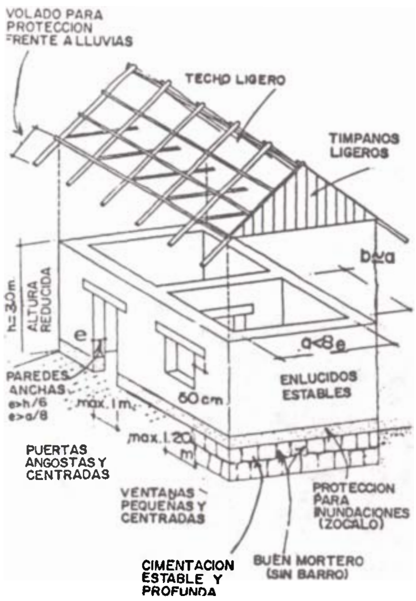
- Simplicidad de ejecución.
- Economía.
- Aislamiento térmico y acústico.
- Producción sin consumo de energía.

Los mayores inconvenientes podrían ser:

- Durabilidad (erosión, humedecimiento, etc).
- Fragilidad frente a desastres naturales (sismos e inundaciones).
- Disminución de las áreas efectivas debido al grosor de los muros.
- Aceptabilidad social.

La tecnología moderna ha desarrollado en las últimas décadas, materiales nuevos, propios de países industrializados. Menos esfuerzo se ha invertido en la solución o control de las deficiencias de los materiales primitivos o naturales, más propios de los países del Tercer Mundo.

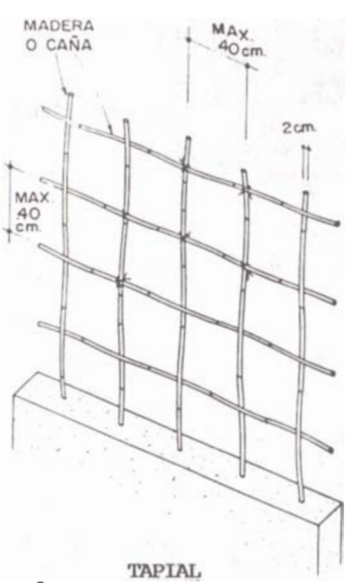
*Autor a quien debe ser dirigida la correspondencia.



- CONSTRUCCIONES DE UN PISO
- HABITACIONES CASI CUADRADAS ($a \simeq b$)
- DISTRIBUCION SIMETRICA DE MUROS
- VANOS PEQUEÑOS
- DISTANCIA MAXIMA ENTRE CONTRAFUERTES 8

CONFIGURACION ADECUADA

Gráfico 1



2a

REFUERZO NECESARIO EN LOS MUROS DE CONSTRUCCION DE TIERRA

Gráfico 2

Una revisión del listado de ventajas y desventajas presentado, nos permite concluir que las primeras son cada vez más importantes en el mundo de hoy; y las segundas son superables con el auxilio de nuevos conocimientos técnicos y programas educativos de apoyo estatal.

Por estas razones, tal vez como consecuencia de alguna ley natural, se podría afirmar que las construcciones de tierra volverán a imponerse en el futuro.

Para lograr la utilización masiva de la construcción con tierra en una sociedad actual latinoamericana, en primer lugar, es necesario desarrollar la información técnica que permita competir al material, con los existentes en el mercado actual.

Esto significa el conocimiento del material en sí y también desde el punto de vista arquitectónico y estructural en base a estudio e investigación que permita desarrollar normas, manuales de diseño, textos, panfletos de difusión práctica, material didáctico a diferentes niveles de formación e información para la educación continua de los especialistas.

Desarrollado lo anterior, al igual que otros materiales, la tierra podrá ser seleccionada por comparación de resultados y costos, por facilidades de diseño, construcción y uso.

Las áreas más rezagadas de estudios, son sin duda las asociadas al comportamiento sísmico y a la durabilidad frente a la humedad o al agua.

<u>Recomendaciones Técnicas</u>

Las recomendaciones que se presentan, son aplicables a las construcciones de tierra en general, pero están especialmente orientadas a la vivienda popular, pretendiendo mejorar la calidad de la construcción espontánea, informal o masiva que es la que mayores pérdidas de vida y daños produce frente a los eventos sísmicos.

No incluye por tanto las soluciones que usan estabilizantes (cemento, cal, asfalto, etc.) para mejorar la resistencia o durabilidad, ni refuerzos utilizando materiales costosos (concreto, acero, etc.) para mejorar su comportamiento dinámico.

Las recomendaciones son el resultado de extensos programas de investigación realizados en los últimos 15 años y fase fundamental para las etapas de Difusión e Implementación (ver notas 1 a 6).

a) Suelos de Fundación: La fragilidad y poca resistencia sísmica de las construcciones de adobe, obliga a limitar los posibles emplazamientos de las construcciones a aquellas áreas asociadas a subsuelos firmes o relativamente firmes.

b) Cimentación: Los cimientos y sobrecimientos para los muros podrán ser de piedra o ladrillo asentados por un buen aglomerante (cemento, cal, yeso, etc). En vista del elevado costo del cemento u otros aglomerantes, su uso debe ser mínimo (como mortero para adherir las unidades). (Ver graf. 1).

El refuerzo vertical nace en el sobrecimiento, para facilitar la construcción del cimiento.

c) Otras Características Apropiadas: Desde el punto de vista del comportamiento sísmico, las construcciones de tierra son peligrosas, ya que los métodos tradicionales no tienen siempre en cuenta que el material es pesado, poco resistente y frágil.

La tecnología moderna debe tender precisamente a aligerarlas, concederles resistencia y ductilidad.

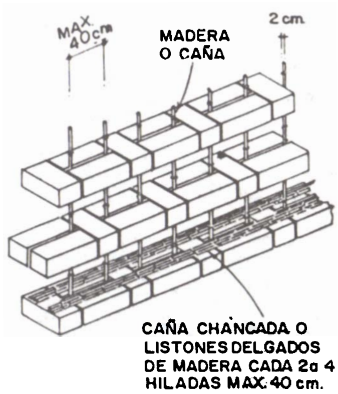
Los techos y tímpanos deben ser muy ligeros, así como la altura de las paredes debe ser mínima.

En la construcción de los muros de adobe, no debe usarse suelos sin suficiente arcilla (ver prueba de resistencia seca). Debe añadirse arena gruesa o paja para controlar o evitar fisuraciones, especialmente en el mortero de junta (ver nota 7).

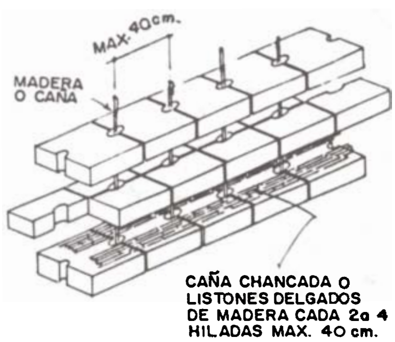
Por razones sísmicas, todas las construcciones de tierra deben tener refuerzos de material de alta resistencia a la tracción y compatibles con el material (madera o caña).

d) Refuerzos: El refuerzo más efectivo para los muros es el de caña o madera, constituyendo mallas amarradas en los nudos y colocadas al interior de los muros en una o dos capas verticales según el espesor de los mismos (Ver graf. 2a, 2b, 2c).

2b



2c



ADOBE
REFUERZO NECESARIO EN LOS MUROS DE CONSTRUCCION DE TIERRA

Gráfico 2

En las construcciones de bahareque o quincha constituyendo marcos de mayor sección, rellenas con mallas secundarias de menor sección (Ver graf. 3a, 3b).

En todos los casos las mallas y marcos deberán estar firmemente conectados a la cimentación y a la viga collar superior que se describe más adelante.

En los nudos y encuentros, las maderas o cañas se unen amarradas con hilo de pescar (nylon) o sustitutos de existencia local (cueros, soguillas, etc).

Conviene colocar una capa de refuerzo horizontal a la altura de los dinteles de puertas y ventanas (bajo los dinteles). Los dinteles deben tener todos el mismo nivel y suficiente longitud de apoyo a cada lado de los vanos.

Los refuerzos horizontales que se encuentran en las esquinas, deben trenzarse y amarrarse eficientemente entre sí.

Todos los muros deben llevar una viga collar continua en la parte superior de los mismos.

Una buena solución es la mostrada en el graf. 4.(ver al final)

La viga collar superior estará unida a la cimentación a través del refuerzo vertical, tal como se vió en el graf. 2, para garantizar el trabajo integral de los muros.

Los dinteles de los vanos también deben ir fijados a la viga cadena superior, para impedir una vibración desordenada. Para ello se puede usar unas cuantas tablitas de madera (Ver graf. 4).

Nótese que en los encuentros de esquina o en T, los refuerzos cubren los contrafuertes o proyección de las paredes. Esta disposición facilita la interconexión de las paredes y de la viga cadena y mejora el comportamiento global.

e) Techos: Los techos tienen dos partes principales: la estructura y la cobertura.

El conjunto debe ser ligero y estar bien conectado entre sí y a los muros.

La estructura descansará sobre la viga collar colocada en los muros o en elementos longitudinales de madera, para distribuir la carga. Se evitará apoyar las vigas sobre la zona de los dinteles y si es inevitable se reforzará adecuadamente dichos dinteles.

La estructura no debe generar empujes laterales sobre los muros y debe garantizarse su propia estabilidad lateral.

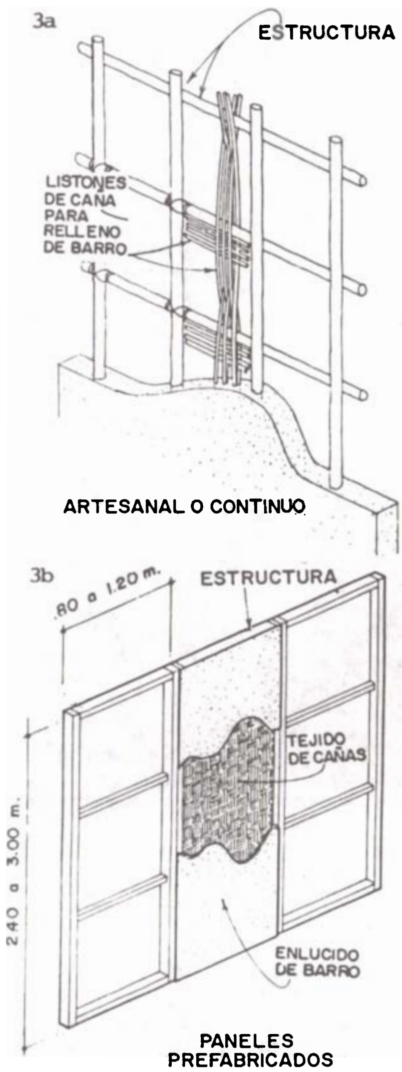
La cobertura garantizará la impermeabilidad del techo. Si se usa algún tipo de paja, se recomienda colocar enlucidos de barro mezclado con algún impermeabilizante o estabilizante.

f) Muros de Adobe o Bloques: Tanto en el bloque cortado como en el moldeado, los bloques más resistentes corresponden a los suelos plásticos o arcillosos. Sin embargo, la resistencia del bloque juega un papel secundario en la resistencia de la mampostería, en la cual son críticas las juntas entre bloques.

Para garantizar la adhesión entre bloques y mortero, debe evitarse la microfisuración de éste. Las condiciones de secado del mortero son muy severas por la velocidad del proceso al ponerse éste en contacto con los bloques ávidos de humedad y por la restricción a la contracción de secado. Esto produce la microfisuración mencionada y la debilidad de la mampostería. Este conocimiento no es tradicional y debe ser cuidadosamente difundido (ver nota 7).

Si el barro de la junta, que normalmente es el mismo utilizado en el bloque, tiene suficiente arcilla de acuerdo a la prueba de resistencia seca, entonces debe observarse si tiene problemas de fisuración. Si los tiene debe añadirse al mortero preferentemente paja, en la mayor cantidad posible siempre que permita una trabajabilidad aceptable (cerca de 1:1 en volumen). También se puede alternativamente, añadir arena gruesa. La proporción adecuada viene dada por la prueba de control de fisuración.

En suelos arcillosos conviene remojar los adobes unos minutos, antes de asentarlos y mojar la capa anterior de bloques antes de colocar el mortero de junta. En suelos arenosos no conviene el remojado. Sólo conviene mojar la capa anterior de bloques.



CONSTRUCCIONES DE TIERRA CON ESTRUCTURA DE MADERA O CAÑA

Gráfico 3

Debe llenarse cuidadosamente las juntas verticales del mortero.

Los bloques utilizados deben estar bien secos para evitar futuras retracciones.

Las dimensiones de los bloques no son muy importantes para la resistencia, ni tampoco el aparejo o disposición de los bloques entre sí.

g) Muros de Tapial: Las construcciones de adobe adquieren resistencia activando la arcilla del suelo por humedecimiento, las de tapial lo hacen por compactación, utilizando menores porcentajes de humedad.

Existiendo arcilla, la mayor resistencia se obtiene con mayor humedecimiento y compactación. Hay sin embargo, por un lado, limitaciones prácticas para limitar el humedecimiento: la factibilidad de poder golpear y compactar el suelo y la excesiva deformabilidad al desencofrar; por otro lado, existe el problema de la fisuración.

Para controlar la fisuración se exige el uso de bajos porcentajes de humedad (del orden de los óptimos en la prueba de Proctor o menores) y el control de la cantidad de arcilla añadiendo a los suelos arena gruesa. Si la cantidad de arena gruesa es excesiva, se disminuye la resistencia peligrosamente. Se recomienda hacer pruebas de muros con distintos porcentajes crecientes de arena, hasta que se controle tolerablemente la fisuración.

La compactación o número de golpes del muro, es función del peso y forma de la herramienta. A mayor compactación, mayores resistencias. Pero llega un momento que la eficiencia no progresa. Se recomienda una compactación normal, que no produzca que pedazos de barro se queden adheridos al encofrado cuando éste se retira. Se recomienda 50 golpes cada 1000 cm^2 con un mazo de 8 a 10 kgs de peso. La altura recomendable para los bloques varía entre 50 y 80 cms, pero es muy importante que las capas de compactado no sean mayores de 10 cms.

La mejor forma de garantizar el monolitismo en las paredes de tapial, es echar paja y bastante agua en las subjuntas de compactado (cada 10 cms).

Asimismo, entre bloques o mejor dicho entre capa y capa de tapial (cada 50 a 80 cms), es necesario echar bastante agua antes de colocar el material superior y compactarlo.

La colocación de piedras, grava o paja entre capa y capa de tapial, no es necesaria, ni útil.

La utilización de paja en la mezcla de barro en cantidades excesivas (mayores de 1:1/4 en volumen) es contraproducente pues disminuye la resistencia.

h) Construcciones de Tierra con Estructuras de Madera o Caña (Quincha): El comportamiento sísmico de este tipo de construcciones puede llegar a ser muy bueno, si es que se observan cinco puntos fundamentales:

- Buenas conexiones entre los elementos de madera o caña, de forma de garantizar un comportamiento integral. Las conexiones normalmente son hechas con clavos. El número y dimensión serán suficientes pero no excesivos como para rajar los elementos. También pueden concebirse uniones amarradas con cueros, soguillas, etc.

- Rigidez lateral en base a algunos elementos oblícuos de arriostre en el plano de la estructura, de manera de disminuir la deformabilidad y por tanto la fisuración del material de relleno de la estructura (normalmente barro).

- Preservación de los elementos de madera y caña, especialmente en la parte embutida en la cimentación, que debe ser de concreto, piedra o ladrillo, estos últimos asentados con morteros de cemento, cal o yeso.

- Adicionalmente es recomendable que el material de relleno consista en mallas de madera o caña de menor sección, sobre las cuales se coloca una capa de barro con paja (1:1 en volumen) por cada cara, a manera de relleno y enlucida. Muchas veces esta malla es tejida entre sí, e incluso alrededor de la estructura principal.

- Tanto en las viviendas construidas como sistema continuo, como en las de paneles prefabricados, debe colocarse una solera o viga continua superior que tiene doble misión:
Garantizar un trabajo integral de todas las paredes;y
Distribuir adecuadamente las cargas del techo.

Sólo después de fijar esta viga cadena superior y el techo (cuando se ha terminado de clavar), deberá ser colocado el relleno de barro, para evitar que éste se desprenda o fisure con los golpes propios del clavado de los elementos.

En el caso de paneles prefabricados, los marcos de los paneles pueden llegar a tener secciones muy reducidas y económicas (1" x 3" ó 1" x 2"). La conexión entre paneles se efectúa con clavos, pero las maderas o cañas tejidas para recibir el relleno de barro, puede no ser clavada.

i) Enlucidos y Pinturas: La finalidad de los enlucidos y pinturas es brindar protección y durabilidad a los muros, además de las razones estéticas.

Los enlucidos en base a aditivos naturales, pueden estar conformados por dos capas. La primera de alrededor de 1 cm, conformada por una mezcla de barro con paja (1:1 en volumen) y un aditivo natural que aumente la resistencia húmeda del barro para impedir su fisuración durante el proceso de secado, que es paralelo a la adquisición de resistencia seca. El aditivo natural ayuda a resistir las tensiones de retracción de secado restringido. La segunda y final, es compuesta por barro de material fino que cuando está casi seco, debe ser frotada enérgicamente con pequeñas piedras redondeadas y lisas de la mayor dureza posible.

Se recomienda como aditivo natural el uso de jugo de cactus mezclado con agua (60 kgs de cactus para 40 litros de agua) para mezclar con la tierra de la primera capa, hasta obtener una trabajabilidad razonable.

Existe otros aditivos naturales de acción semejante, tales como la resina de algarrobo, o el agua del hervido del árbol de banana, etc.

Aunque no siempre se puede disponer de bitumen y tampoco es económico, es posible utilizar enlucidos preparados en base a este material.

Las pinturas deben preferentemente ser insolubles en agua para proteger a los muros de las lluvias.

Se utiliza lechadas de cal, de cemento, de yeso, aceites y también extractos de plantas.

Generalmente, las pinturas modernas de origen químico o sintético, tienden a formar barreras contra la humedad pero sólo proporcionan protección temporal, pues se desprenden.

Conclusiones

- La situación socio-económica de ciertos países latinoamericanos es tal, que requiere soluciones de vivienda de muy bajo costo, como la de construcción con tierra (adobe, tapial, quincha, etc).

- El proceso de desarrollo de programas de construcciones con tierra, exige previamente estudio, investigación, difusión del conocimiento, elaboración de normas, discusión técnica internacional, etc., para que el material pueda competir técnicamente con materiales más resistentes y costosos.

- El esfuerzo realizado en investigación en el Perú, Guatemala, México, etc., debe ser continuado y complementado con las fases de discusión y divulgación, de manera de lograr que el material sea aceptado por la comunidad profesional internacional primero y por los gobiernos y usuarios después.

ANEXO

Prueba de Resistencia Seca

Se fabrican tres o más bolitas pequeñas de suelo de aproximadamente 2 cm de diámetro. Una vez secas (a las 24 horas) se aplasta cada bolita entre los dedos pulgar e índice. Si las bolitas son tan fuertes que ninguna se puede romper, el suelo tiene suficiente arcilla para ser usado en la construcción con adobe, siempre y cuando se controle la microfisuración del mortero debida al secado. Si algunas bolitas se rompen, el suelo es inadecuado, ya que le falta arcilla y deberá descartarse.

Prueba de Control de Fisuración

Se fabrica por lo menos ocho emparedados, con morteros hechos con mezclas en proporciones gradualmente decrecientes de suelo y arena gruesa. Se recomienda que las proporciones suelo/arena gruesa, varíen entre 1:0 y 1:3 en volumen. El emparedado con el menor contenido de arena gruesa que, al abrirse a las 48 horas, ya no muestre fisuras visibles en el mortero, indicará la proporción suelo/arena más adecuada para la construcción con adobe, de mayor resistencia.

NOTAS

1. M. Corazao, M. Blondet, "Estudio Experimental del Comportamiento Estructural de las Construcciones de Adobe frente a Solicitaciones Sísmicas", Premio Sayhuite, Banco Peruano de los Constructores, Lima, 1973.

2. M. Blondet, J. Vargas, "Investigación sobre Vivienda Rural", Pontificia Universidad Católica del Perú - Convenio Ministerio de Vivienda, 1978.

3. J. Vargas-Neumann, "Vivienda Rural en Adobe", Publicación DI-78-01, Departamento de Ingeniería, Pontificia Universidad Católica del Perú, 1978.

4. J. Vargas-Neumann, G. Ottazzi, "Investigaciones en Adobe", Publicación DI-81-01, Departamento de Ingeniería, Pontificia Universidad Católica del Perú, 1981.

5. J. Vargas-Neumann, "Albañilería de Adobe con Variaciones de Mortero", Publicación DI-79-02, Departamento de Ingeniería, Pontificia Universidad Católica del Perú, 1979.

6. G. Ottazzi, J. Vargas-Neumann, "Investigación Comparativa sobre la Resistencia del Adobe", IV Congreso Nacional de Ingeniería Civil, Chiclayo, 1982.

7. J. Vargas-Neumann et al, "Seismic Strength of Adobe Masonry", Publicación DI-84-01, Departamento de Ingeniería, Pontificia Universidad Católica del Perú, Abril 1984.

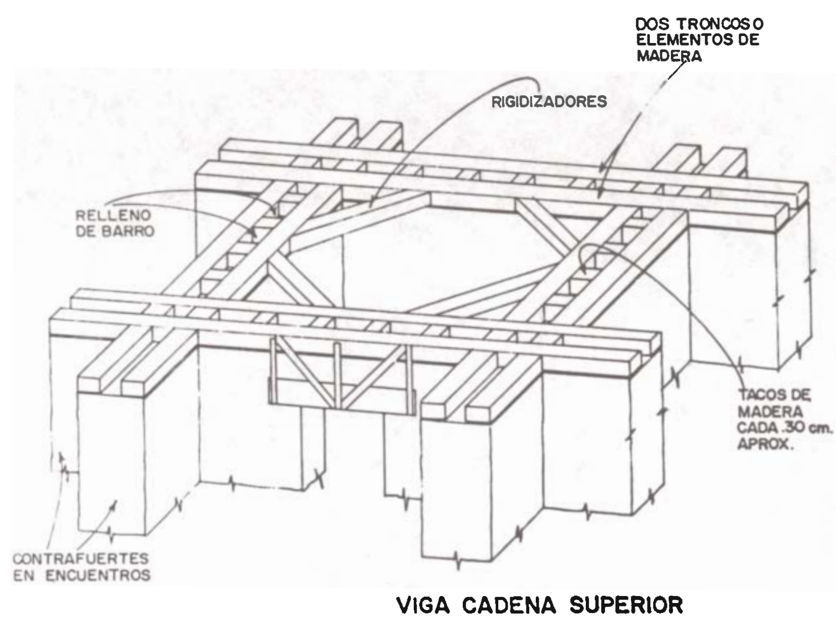


Gráfico 4

Site Preservation

THE HOUSE THAT JUAN BUILT: AN ARCHAEOLOGICAL PERSPECTIVE ON ADOBE ANALYSES

Jeffrey L. Boyer
Staff Archaeologist
Office of Archaeological Studies, Museum of New Mexico
P.O. Box 2087
Santa Fe, New Mexico 87504-2087
U.S.A.

ABSTRACT

Architecture often comprises one of the most conspicuous features on archaeological sites. However, archaeologists have generally not paid the same attention to architecture as to other human artifacts.

Using data from the Trujillo House (LA 59658), a 19th century Hispanic homestead near Abiquiu in the Rio Chama Valley, the Office of Archaeological Studies of the Museum of New Mexico is exploring the utility and potential of adobe analyses in archaeological research. Analyses of adobe building materials from the site show that the adobe was made on-site using local materials. The very sandy soil was made sandier by the addition of coarse sand to the adobe, producing adobe that was weaker than the native soil. Comparison of material from a post-1880 borrow pit with adobe from the structure shows significant differences with adobe from rooms probably pre-dating the pit, thus clarifying the construction sequence of the house.

Analyses of adobe from the Trujillo House show potential for providing information on changing frontier settlement, site formation processes, and the use of local and regional construction materials.

KEYWORDS

Hispanic architecture, archaeology, adobe, particle size, plasticity, soluble salts.

Introduction

Because architecture often comprises the most conspicuous feature of an archaeological site, archaeologists have been forced to study architecture as they would any other human artifact. However, while archaeologists have developed a wide variety of techniques to study artifacts such as ceramic sherds, stone tools, and glass or metal items, we have typically not studied architecture as a human artifact.

The Office of Archaeological Studies of the Museum of New Mexico is incorporating analyses of adobe building materials into archaeological data recovery projects in north-central New Mexico. The research design for the Abiquiu Project (MNM Project 41.405) involves investigating the development of Hispanic and Puebloan sociocultural frontiers. Using data from this and other projects, the Office of Archaeological Studies is exploring the potential of adobe analyses for illuminating patterns of local and regional material use, settlement, site formation processes, and for testing oral tradition.

The Trujillo House (LA 59658)

In 1988, the Office of Archaeological Studies conducted archaeological data recovery investigations at four sites in the Rio Chama Valley immediately east of the village of Abiquiu (Fig. 1). The sites were recorded during an archaeological inventory survey of U.S. Highway 84 prior to planned reconstruction activities.(1)

One of these sites was described as "a dense refuse deposit measuring roughly 23 by 10 m... Although no structures were observed, noticeable vegetation changes suggest areas of occupation. The dense trash deposit is characteristic of domestic refuse, suggesting a historic residential occupation."(2) Data recovery at this site included archival and ethnohistorical research as well as extensive archaeological excavations.

Archival research revealed that the site was located on lands once belonging to the family of Jose de Uribarri, a *genizaro* who settled in Santa Tomas de Abiquiu in 1754. Although the family history is somewhat cloudy due to the nature of the church baptismal and marriage records, it appears that Uribarri's great-granddaughter, Juana Maria Jaramillo, married one Juan Esteban Trujillo. The year of their marriage is not clear, but their first child was born in 1838. The land was sold in 1872 and again in 1884, but Trujillo continued to maintain his residence there. An 1894 map of the Abiquiu area shows the "house and land of Juan Trujillo" at the location of the archaeological site. The house was apparently abandoned soon thereafter.(3)

Excavations at the site confirmed the archaeological survey and archival information by revealing the remains of an eight room, C-shaped adobe structure and a deep trash-filled pit (Fig. 2). The house measured 34.5 m long by 10.5 m wide and faced northwest. The wall remnants were no taller than 50 cm in the center of the house and were missing at the north ends of Rooms 1 and 7, due both to highway construction and to the subsequent burial of a telephone line along the right-of-way fence.

The Trujillo House was constructed of adobe bricks. In some portions of the structure, the bricks could be defined along the top and sides of the wall remnants. However, natural deterioration of the adobe meant that individual bricks could not always be defined. The walls were plastered with one or more layers of adobe plaster and were then covered with very thin layers of gypsum whitewash known locally as *jaspe*. *Jaspe* is not a Spanish word and may have been borrowed from Jicarilla Apaches who frequented the area in the 18th and 19th centuries.

The most common features in rooms were fireplaces, which were typical Hispanic corner fireplaces except that only two fireplaces were actually built in room corners. The other fireplaces were built in artificial corners formed by short wing walls. In each

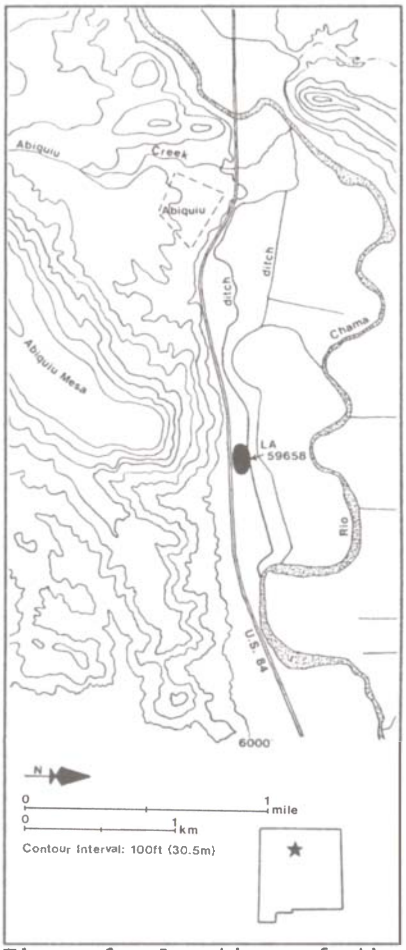


Figure 1. Location of the Trujillo House (LA 59658).

case, the wing walls created a barrier between the fireplace and the door leading into the room, probably protecting the fireplaces from drafts and so increasing their efficiency.

Besides doors, only two other features were recorded in the house. A dismantled *banco* (bench) was found in the northeast corner of Room 1 and an undefined feature was found in Room 7.

The trash-filled pit was located about 6.5 m north of the structure and was identified during survey as a dense scatter of surface artifacts. Excavation revealed a pit 1.6 m deep and 5.4 m in diameter that had been dug into sterile, natural soil.

Adobe Building Materials at the Trujillo House

A. Samples and Analytical Methods

Five adobe brick samples and six adobe plaster samples were collected from the Trujillo House (Fig. 2). In addition, two samples were collected from the midden pit, intended to provide control data for the analyses. One sample was collected from the south side of the pit about .5 m below present ground surface. The second sample was collected from the bottom of the pit.

Of the 13 samples, 11 were selected for analyses. These included both samples from the midden pit, the five brick samples, and four plaster samples. Table I lists the proveniences and types of these 11 samples.

The liquid and plastic limits of each sample were determined using methods outlined by Teutonico.(4) Particle size analyses of seven samples were conducted using a sieve stack ranging from 2 mm to .075 mm and the sedimentation-hydrometer method for particles smaller than .075 mm.(5) Finally, Teutonico's qualitative methods were used to test for water soluble salts in seven samples.(6)

B. Analytical Results

1. Particle Size The percentages of coarse and fine sands, silt, and clay in the control sample, three brick samples, and three plaster samples are presented in Table II. Fine sand constitutes the primary ingredient in each sample, ranging from 54 to 75 percent. Coarse sand is the most diverse ingredient, ranging from 1 to 24 percent. Silt ranges from 12 to 24 percent, while clay is present in amounts ranging from 0 to 12 percent.

The control sample from the midden pit contains a very low percentage of coarse sand, a high percentage of fine sand, a moderate percentage of silt, and the highest percentage of clay. The most similar adobe sample is from the hearth floor in Room 3, which is also low in coarse sand and high in fine sand but is much lower in clay. The other samples contain between 3.3 and 6.7 times as much coarse sand as the control sample, while their relative clay contents are 27 to 60 percent less. The brick and plaster samples from Room 2 have the highest clay contents. Sample 4 from Room 4 is aberrant because no dispersing agent was used in processing the sample. Probably for that reason, the percentage of coarse sand is much higher than in the other samples and no clay was recorded.

In order to compare the Trujillo House samples with modern construction standards, the percentages of coarse and fine sands and of silts and clays were combined. This data is presented in Figure 3, which shows the percentages of sands and silt/clays in comparison to standards set by the U.S.D.C. National Bureau of Standards (7) and Section 2405 of the Uniform Building Code.(8) The midden control sample (sample 1) falls near the bottom of the NBS standards for sand but near the middle of the range for silt/-clay. The adobe samples fall below the midpoint of the standards for both sand and silt/clay, indicating that the adobe samples have slightly less clay than recommended, important since clay acts as a binder in adobe.

A different picture is obtained, however, when the samples are compared to the Uniform Building Code standards. The percentages of sand are at or above the midpoint of the range for sand while the percentages of silt/clay are well below the midpoint of the range for silt/clay. This suggests that the adobe samples contain more sand and less clay than recommended standards; since clay is the binder, these sandy adobes would be relatively weak, perhaps weaker than the natural soil.

2. Plasticity Liquid and plastic limits were calculated for all

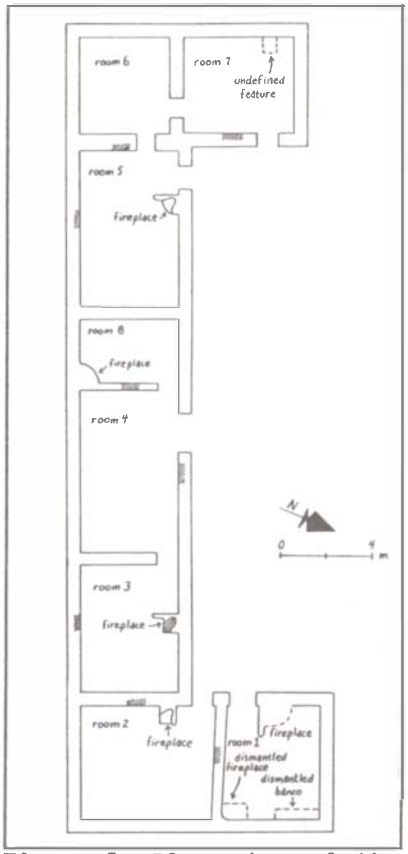


Figure 2. Plan view of the Trujillo House showing features and adobe collection locations (////).

11 samples. The results of these tests are presented in Table II. Figure 4 graphically shows the relationship between the liquid and plastic limits for each sample. It is important to note that only the control sample and two plaster samples have positive indices. All other indices are negative. However, even the positive indices are quite low, indicating that the soil, both natural and as adobe, is essentially non-plastic. This is probably due to the relatively high sand and low clay contents.

Interestingly, the midden floor sample resembles the adobe samples much more closely than it does the control sample. In fact, the plasticity of the midden floor sample is almost identical to that of the wall dividing Room 4 into Rooms 4 and 8 and is quite similar to the samples from Room 2 and from the hearth in Room 3. Although this sample was collected as a control, it appears that it may actually be adobe rather than natural soil. This could not be confirmed by particle size analysis as time did not permit additional tests.

As noted above, the plaster samples from Rooms 5 and 7 are the only adobe samples with positive indices. The brick samples from these two rooms, although possessing negative indices, have the highest indices of the remaining adobe samples. These facts set Rooms 5 and 7 in a cluster of indices well below that of the control sample but above the other adobe.

The sample from Room 4 is singular in its very low index. This sample also had the most diverse liquid limit test figures, perhaps pointing to material diversity within the sample.

3. Soluble Salts The results of the qualitative tests for soluble salts in seven samples are presented in Table II. Tests for the presence of nitrates could not be carried out because the lab lacked the necessary acids and reagents. However, it may be presumed that nitrates are present where nitrites are found. The data show that the midden floor sample contained the widest range of salts, including sulfates, chlorides, nitrites, and carbonates. Only carbonates were strongly present and the identification of sulfates was tentative.

Two samples are similar to the midden floor sample in the presence of salts-sample 2 from Room 2 and sample 3 from the hearth in Room 3. Sample 6 from Room 7 may also be similar but the presence of chlorides could not be positively identified. The remaining samples are similar to each other but not to the midden floor sample.

In general, soluble salts are not strongly present in any of the samples. This may have to do with the high sand content of the soil and adobe, which would facilitate draining water away from the adobe walls rather than holding it in the walls where salts would be deposited.

4. Plaster Layers In addition to the materials analyses, the six plaster samples were visually inspected to determine the number and thickness of plaster layers and number of layers of *jaspe*. Two samples show only one plaster layer; both are from Room 2. The average thickness of six fragments from the west wall is 13.6 mm, while the fragment from the north wall is 22 to 24 mm thick. One *jaspe* fragment from the west wall has six layers, each less than .25 mm thick.

Plaster samples from Rooms 3 and 5 show two plaster episodes. Three fragments from the two rooms may point to a third plaster layer. The evidence from Room 3 consists of possible remnants of *jaspe* on the interior surface of one fragment, while the evidence from Room 5 consists of a thin discontinuous layer on the exterior of one fragment from the south wall and a third exterior layer on a fragment from the west wall. However, six other fragments from the south and west walls of Room 5 have only two layers. Consequently, evidence of a third plaster layer is not substantial and may point to incomplete replasterings of those rooms.

Two fragments from Room 7 point to three plasterings. One fragment has three distinct layers, while the second has two layers with a remnant of *jaspe* on the interior surface.

Interpreting the Results

The potential of adobe materials analyses in archaeological research rests in the ability of the analyses to provide data relevant to research issues. The adobe material from the Trujillo House has yielded information useful in addressing at

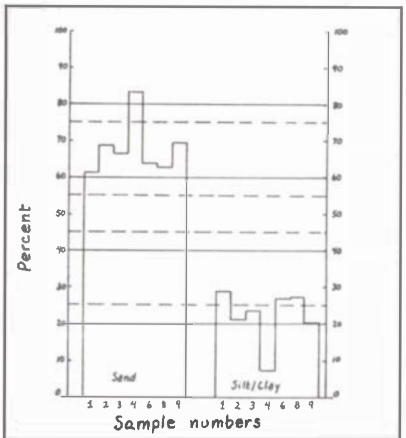


Figure 3. Comparison of Trujillo House adobe with modern construction standards. Solid lines: United States Department of Commerce National Bureau of Standards; Dashed lines: Uniform Building Code.

least three major research questions.

A. Where Was The Adobe Made?

Comparison of the samples taken from the side and bottom of the midden pit reveals that the samples are very different. This is most obvious in Figure 4, where it can be seen that the midden floor sample is quite similar to adobe samples from Room 2, the hearth in Room 3, and the wall separating Rooms 4 and 8. In contrast, the sample taken from the side of the midden pit is a different color than the adobe samples, has different percentages of particle sizes, and a higher plasticity index than the adobe samples and the midden floor sample. This strongly suggests that the control sample from the side of the midden is natural soil. The midden floor sample, on the other hand, was actually adobe that was left in the bottom of the mixing pit.

This is significant for several reasons. First, it identifies the midden pit as an adobe borrow/mixing pit. It seems clear that this feature was initially excavated in order to provide adobe for the house and that, subsequently, the large hole was filled with domestic trash. While we suspected this to be the case, we would not demonstrate it until completion of the adobe analyses.

Second, identification of the borrow pit demonstrates that the Trujillo House adobe was made of local, on-site materials. While this may seem a conclusion too obvious to mention, its significance lies in contrast to an oral tradition from the Taos area to the northeast. Oral tradition in the Taos area maintains that, while adobe was sometimes made on-site historically, there are deposits of clay and sand that were and still are considered to be optimal for adobe. Further, tradition maintains that this "good dirt" was sought by adobe-makers throughout the Taos Valley. This indicates a preference for non-local materials and for regional use of materials from specific locations. This kind of regional use is still being practiced by those in the Taos area who plaster their interior walls with *tierra blanca*, a micaceous kaolin soil found in one deposit in the foothills south of Taos. However, the "good dirt" adobe deposits are located on the Taos Pueblo Indian Reservation and on private lands and are no longer available for general use. Begrudgingly, Taoseños are now forced to make adobe on-site. How accurate the tradition is in showing regional use of specific resources, or whether it actually reflects popular dissatisfaction over the splitting up of the land and the reluctance of landowners to allow access to their lands, is not presently clear. However, it could be tested with analyses of adobe from historical and archaeological contexts. This points out the need for a regional approach to collection and analysis in order to assess the use of local versus regional material sources.

B. How Was The Adobe Made?

Comparison of the adobe samples with the control sample shows that the primary difference between adobe and natural soil at the Trujillo House is that the adobe has a higher coarse sand content and a lower clay content. This suggests that the adobe was made by adding coarse sand to the natural soil. While this may have served to add larger particles to the mix that might act like temper in pottery, its effect was to decrease the relative content of clay, the actual binder in the adobe. The result of this procedure was to produce adobe that was actually weaker than the natural soil due to its high sand and low clay content. This weakness is reflected in the plasticity of the samples. Whereas the natural soil has a positive, albeit low, plasticity index, the plasticity of the adobe is consistently lower and even negative, demonstrating that the adobe from the site is essentially non-plastic. Interestingly, in each case where plaster and brick samples from the same room were analyzed, the plaster has a higher index than the brick, suggesting that the plaster was slightly stronger than the bricks.

The exception to this procedure is the sample from the hearth in Room 3. In this case, the amount of coarse sand is actually lower than the natural soil, while the fine sand is higher. This suggests that the adobe used to plaster the hearth was made by adding fine sand to the mix. While this probably contributed to a finer, smoother plaster, it still decreased the clay content.

There is evidence of historical continuity in the making of weak adobe in the Abiquiu area. In 1982, the New Mexico Bureau of Mines and Mineral Resources published the results of a survey of modern commercial adobe-makers in New Mexico.(9) The survey included several tests of sample bricks. Among the traditional adobe-makers whose bricks were tested for compressive strength, modulus

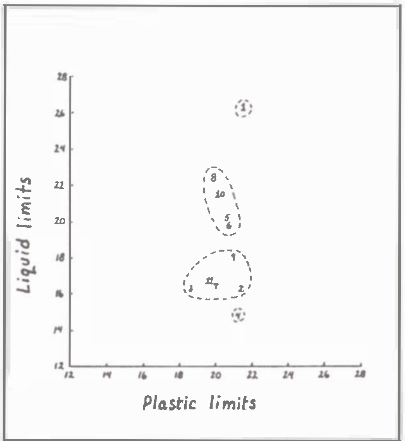


Figure 4. Plasticity, Trujillo House adobe. Each number refers to a sample number.

of rupture, water absorption, and moisture content was one adobe yard in Abiquiu. While the Uniform Building Code (New Mexico State Building Code) requires an average compressive strength of 300 psi, the adobes from Abiquiu averaged only 196 psi. Of the 47 other adobe-makers whose bricks were tested, only three provided samples with lower compressive strength, and two of those were damaged in route to the testing facility. Clearly, the sandy soils of the Abiquiu area are not conducive to making strong adobe.

C. What Was The Construction Sequence Of The Trujillo House?

Wall thicknesses indicate that rather than being built as a single building, the Trujillo House grew as a series of four units over a period of time. Rooms 1 and 2 constituted one unit. The wall separating these two rooms directly abutted the exterior walls rather than being built into the exterior walls and was made of bricks laid end to end so that it was narrower than the exterior walls, which were made of bricks laid side to side.

Rooms 3, 4, and 8 also constituted a single unit. The walls surrounding these rooms were thick exterior walls, including the wall separating Room 3 from Room 2. As with Rooms 1 and 2, it appears that a large room was built that was subsequently divided by narrow interior walls. This is supported by wall abutment patterns, in which plaster on the south wall of Rooms 3, 4, and 8 continued behind the wall abutments separating the rooms. In addition, the adobe floor continued under the two dividing walls.

Room 5 was added to the west end of the Room 3-4-8 block as a single unit. The wall between Rooms 8 and 5 was a thick exterior wall and there was no continuity of plaster or floor between the rooms as there was in Rooms 3, 4, and 8. Rooms 6 and 7 were built as a single unit and subsequently subdivided. Plaster on the west walls of Rooms 6 and 7 was continuous behind the wall abutment separating them. The dividing wall was narrower than the surrounding exterior walls.(10)

Though it is plain that the structure grew by accretion, the actual sequence was difficult to discern as natural deterioration of the adobe had obscured some wall abutments. For instance, it was clear that a thick exterior wall separated the Room 1-2 unit from the Room 3-4-8 unit, but whether it was originally the east wall of Room 3 or the west wall of Room 2 was not clear.

Comparison of the samples demonstrates that there were distinct similarities between the adobe from the midden floor and that from three locations in the house - Room 2, the hearth floor in Room 3, and the wall dividing Rooms 4 and 8. This is seen clearly in the plasticity and salts tests. Analyses of the artifacts from the six cultural strata in the pit strongly suggest that the artifacts were deposited in the pit after about 1880 or perhaps slightly earlier.[11] This suggests that modifications made to the house using adobe from the pit also date from the last years of the occupation. Therefore, it may be conjectured that Room 2 was built late in the site's history, probably during the last building episode. This is supported by the plasticity data and the soluble salts, as seen in Figure 4 and Table II. It is also supported by the plaster layer data, from which it is seen that Room 2 is the only room with a single plaster layer, in contrast to Rooms 3, 5, and 7, where two and three plasterings are evident. Since it is clear that Rooms 1 and 2 were built as a unit, this unit was probably the last portion of the house to be built.

As noted above, plaster on the southern wall of Room 4 demonstrates that this wall and, therefore, Room 8 were built after construction of Room 4. It may be conjectured that the wall dividing Room 4 into Rooms 4 and 8 dates from the same late building episode that produced Rooms 1 and 2. This is supported by the plasticity data, which points to a strong similarity between the midden adobe and the Room 4/8 wall.

Finally, although Room 3 had evidence of two or three plastering episodes and so was perhaps one of the older rooms, the fireplace was apparently remodeled or at least replastered at the same time that Rooms 1 and 2 were built and Room 8 was divided from Room 4.

Using wall thickness data and the results of materials analyses, the following scenario may be postulated for the construction sequence of the house. Rooms 3 and 4 were built as the original house, perhaps as early as the late 1830s. Sometime later, Room 5 was added to the west end of the house. It remained a separate unit as no door was made to connect it to Room 4. Rooms 6 and 7 were built as a unit on the west side of Room 5 and connected to the latter by a door, resulting in a larger, three-room unit on the west end of the house. The presence of two and three plaster layers in Rooms 3, 5, and 7 suggests that the house grew to that size fairly rapidly and remained in that form until about 1880, being subjected to the same maintenance activities. Sometime around 1880, Rooms 1 and 2 were built as a unit on the east end of the house, Room 4 was subdivided into Rooms 4 and 8, and the fireplace in Room 3 was remodeled or replastered. Finally, between that time and the time of abandonment about 1894, Room 1 was extensively remodeled.

Conclusions

Analyses of adobe building materials have yielded significant information on construction processes at the Trujillo House. The analyses demonstrate that the adobe used at the site was made on-site. Further, a large trash-filled pit was positively identified as a borrow/mixing pit, clarifying processes of site formation.

The natural soil at the Trujillo House is not well suited for adobe, although it falls within modern construction standards. If the Trujillos had used the natural soil alone, the adobes might have been stronger. However, by adding additional sand, the relative clay content of the soil was decreased, making it weaker and non-plastic.

Finally, the analyses have been critical in determining the construction sequence of the house by providing data which, when linked with artifactual studies, allow us to assign dates to construction episodes and to portions of the structure. As a consequence, the growth of the house from its original two rooms to its final eight is better understood.

These data are important in themselves with specific reference to the Trujillo House. However, they raise questions about material use and site formation processes that require a regional perspective. What are the quarry sources for *jaspe*? If the use of *jaspe* represents regional use of a specific material, why does the adobe reflect use of on-site materials? Are there no regional sources for better adobe soil? How does the size of a dwelling reflect the length of occupation? What is the relationship between dwellings and other features on a site? A body of regional data will show the utility of adobe materials analyses in addressing regional archaeological issues.

The Trujillo House data have important implications for conservationists as well. Material compatibility between original adobe and that used for stabilization, reconstruction, or maintenance could best be ensured by using materials from the same for similar sources. This should reduce the risks of differential weathering, moisture absorption, and weight-bearing strength. However, identification of material sources and construction techniques raises an issue of the desirablilty of identical materials in conservation. Were the Trujillo House to be stabilized or reconstructed, the conservationist would need to consider whether such weak adobe would be suitable in the face of long-term maintenance and stability needs. Finally, there is the consideration of the use of materials from different sources in the same structure, which would require both identification of the various sources and assessment of material compatibility and suitability for use throughout the structure. These concerns point to the need for regional data collection and suggest an important partnership between archaeology, ethnohistory, and conservation.

Table I. Sample numbers, proveniences, and types, Trujillo House adobe.

Sample	Provenience	Type
1	Midden pit, south wall, .5 m below present ground surface	Natural soil control
2	Room 2, west wall	Brick
3	Room 3, hearth floor	Plaster
4	Room 4, north wall	Brick
5	Room 5, west wall	Brick
6	Room 7, east wall	Brick
7	Rooms 4 and 8, wall	Brick
8	Room 7, east wall	Plaster
9	Room 2, north wall	Plaster
10	Room 5, south wall	Plaster
11	Midden pit floor	Adobe

Table II. Summary of analytical results, Trujillo House adobe.

Sample	Particle Size in %[a]				Plasticity in %[b]			Salts[c]			
	cs	fs	s	cl	ll	pl	pi	s	ch	n	c
1	3.56	67.72	16.59	12.12	26.30	21.49	4.81				
2	16.55	62.28	14.02	7.14	16.25	21.49	-5.24	-	+/-	+	++
3	1.60	74.56	18.77	5.07	16.30	18.50	-2.20	-	+/-	+/-	+
4	24.01	68.90	7.10	0	14.70	21.20	-6.50	-	-	+/-	+
5					20.23	20.64	-.41	-	-	+/-	+
6	13.30	60.66	19.63	6.54	19.70	20.63	-.93	+	?	+/-	+
7					16.60	19.96	-3.36	-	-	+/-	+
8	17.74	54.90	24.06	3.28	22.50	19.94	2.56				
9	11.97	67.82	12.94	7.27	18.00	21.00	-3.0				
10					21.60	20.13	1.47				
11					16.75	19.78	-3.03	+/-	+	+	++

[a]Particle Size - cs:coarse sand; fs:fine sand; s:silt; cl:clay.
[b]Plasticity - ll:liquid limit; pl:plastic limit; pi:plasticity index.
[c]Soluble Salts - s:sulfates; ch:chlorides; n:nitrites; c:carbonates; ++:strongly present; +:present; +/-:indications inconclusive, perhaps present; -:not present; ?:un known.

REFERENCES CITED

1. Charles A. Hannaford and Timothy D. Maxwell, Survey Report and Research Design for Sites along U.S. 84 Between the State Road 96 Junction and Abiquiu, Rio Arriba County, New Mexico, Laboratory of Anthropology Notes 394 (Santa Fe, Museum of New Mexico, 1987).

2. Ibid, 14.

3. Stanley Hordes, LA 59658: Historical Overview, Manuscript on file, Museum of New Mexico (no date).

4. Jeanne Marie Teutonico, A Laboratory Manual for Architectural Conservators (Rome, ICCROM, 1988), 96-110.

5. Ibid, 83-95.

6. Ibid, 56-69.

7. James R. Clifton, Paul W. Brown, and Carl R. Robbins, Methods for Characterizing Adobe Building Materials, NBS Technical Note 977 (Washington, D.C., USDC National Bureau of Standards, 1978), 12.

8. Edward W. Smith, Adobe Bricks in New Mexico, Circular 188 (Socorro, New Mexico Bureau of Mines and Mineral Resources, 1982), 15, 68-73.

9. Ibid.

10. James L. Moore, Daisy F. Levine, Jeffrey L. Boyer, and Karen Wening, "Trujillo House (LA 59658)," in Adaptations on the Anasazi and Spanish Frontiers (tentative title) by James L. Moore, Jeffrey L. Boyer, and Daisy F. Levine (Santa Fe, Museum of New Mexico, Manuscript in preparation).

11. Ibid.

The Protection and Conservation of the Adobe Structures at Paquimé, Casas Grandes, Chihuahua, Mexico

Roy B. Brown, *
Centro Regional Chihuahua
Instituto Nacional de Antropología e Historia
Juárez y Carranza
31000 Chihuahua
México

Beatriz Sandoval and Haydee Orea M.,
Dirección de Restauración del Patrimonio Nacional
Instituto Nacional de Antropología e Historia
Ex-Convento Churibusco
Xicotencatl y General Anaya S/N
Col. Churibusco, México D. F.
México

* Author to whom correspondence should be addressed.

Abstract

The archaeological site of Paquimé, Casas Grandes, is located in the grasslands of northern Mexico. Paquimé is a prehispanic rammed earth city that reached its heyday in the fourteenth century. Discussion centers on the factors contributing to the deterioration of adobe at Paquimé and the steps that have been taken to preserve the building known as Unit 6. The conclusion presents comments on the steps that need to be taken to insure the site's conservation and protection.

Keywords:

ARCHAEOLOGY, PAQUIMé, CONSERVATION, PROTECTION, ADOBE, RAMMED EARTH

Introduction

Five hundred to a 1000 years ago the site of Paquimé near Casas Grandes, Chihuahua, Mexico, dominated northwestern Chihuahua (Phillips 1989). The early pit houses were replaced by wattle and daub compounds which in turn were replaced by rectangular, single story, rammed earth compounds. These compounds were transformed into the apartment blocks which dominate today's vista.

Apart from the construction techniques, the diagnostic architectural complex includes a freshwater-*cum*-drainage system colonnades, sleeping nooks, stylized hearths, turkey and macaw pens and "T" shaped doorways. The walls are made in standard widths roughly equivalent to 25, 40, 80 and 120 cm. Non-habitational areas include rubble core/stone veneer ceremonial structures such as platform mounds and "I" shaped ball courts (Di Peso 1974; Di Peso, Rinaldo and Fenner 1974).

Paquimé, lies in the Chihuahuan grasslands of the Basin and Range Province of western North America at 30° 25′ N: 107° 52′ W, at 1485 m above sea level. It is about 20 km east of the Sierra Madre Occidental. Paquimé sits on the first terrace of the western bank of the Casas Grandes river.

The climate is arid (300 mm) and extreme (Cetenal 1977; Córdoba *et al.*, 1969; Schmidt 1975, 1983). Most rain falls in torrential summer storms. The extreme summer temperatures surpass 40° C while the extreme winter temperatures dip below 17 °C. Spring winds, westerlies and souwesterlies, reach peak velocities > 17 m/sec. Winter northers reach velocities > 13 m/sec. Soils are shallow, immature and calcareous.

Between 1958 and 1961 Charles Di Peso, Director of The Amerind Foundation led the Joint Casas Grandes Expedition in collaboration with the National Institute of Anthropology and History, a branch of the Mexican government (Contreras 1958; Di Peso 1960, 1966, 1968, 1974; Di Peso, Rinaldo and Fenner 1974).

The four principal factors leading to the deterioration of Paquimé are water (rain, run-off, and capillary action); wind abrasion; expansion and contraction due to temperature changes; and, abrasion etc. due to visitors.

The three main criteria for the development of a research strategy and a management plan are the need to protect the site's scientific worth, educational value and esthetic integrity.

Material presented in this paper without specific attribution is derived from Di Peso (1974) and Di Peso, Rinaldo and Fenner (1974).

Cultural History

Di Peso provided a three period, nine phase chronology based on dates derived from radiocarbon, tree-ring, and obsidian rehydration measurements. Subsequent work has modified the chronology (Dean and Ravesloot 1988; Le Blanc 1980; Lekson 1984). Phillips (1989) proposes an alternate chronology that eliminates some phases and combines others:

Tardio Period;	San Antonio de Padua Phase	AD 1660-1686
Medio Period;	Paquimé, Diablo and Robles	AD 1300-1450
	Buena Fé Phase	AD 1150-1300
Viejo Period;	Perros Bravos Phase	AD 1075-1150
	Pilon Phase	AD 975-1075
	Convento Phase	AD 975- 600

The Viejo Period: The Viejo Period reflects the expansion of the local population as pit-house villages grew and were replaced by rectangular wattle and daub surface compounds. The beginning of this period was related to the downfall of Teotihuacan and the end was related to the rise of Tula (Di Peso 1974).

The Medio Period: Casas Grandians managed to accumulate large quantities of shells, copper bells, metates, etc. and produced large quantities of macaw and turkey feathers. These products were exchanged for cosmic legitimization (Rathje, Gregory and Wiseman 1978).

The Tardío Period: The Tardío Period includes the post climax occupation around Paquimé and the first Spanish intrusions.

Construction Techniques

Since everyone knows what adobe is, adobe is different things to different people (Judd 1977). In this paper we will consider adobe to be a mixture of clayey soils and sand that have been used in construction (Judd 1977). The ideal percentage of clay should be under 20%, while the sand should surpass 45%.

As clay dries, it shrinks, looses its lubrication water and sets in a particular shape. Once the adobe had been set, subsequent addition of water will rehydrate and "melt" the clay. To protect their form most adobe structures are roofed and plastered. When the protection is lost, water penetrates and re-initiates the re-hydration process which results in "adobe rot".

At Paquimé the basic construction material is the local soil which naturally has a high proportion of montmorillonite clay and caliche. No organic matter was added to the soil.

Since cracking was slight, it seems as if the walls were made with a fairly dry mixture of water, mud and gravel. Non-load bearing walls were about 25 to 30 cm wide while load-bearing walls were about 40, 80 or 120 cm wide. The thinner walls supported single story structures while the thicker walls supported multi-storied structures. Although sixteenth century documents mention six or seven floors (Obregon 1986), archaeological evidence suggests there were only three or four.

Both interior and exterior walls were plastered. First the wall core was covered with a layer that provided a level surface for the application of the finishing layer. This penultimate layer plays two very important rôles. Firstly, it creates a smooth and uniform surface that increases the adhesion of the final layer. Secondly by adsorbing any irregularities in the outer surface of the core it reduces the mechanical and hydraulic stresses that tend to crack the final layer.

Conservation and Preservation

The Degradation of Adobe at Paquimé: The four principal factors leading to the degradation of adobe at Paquimé are water (rain, run-off, and capillary action); wind abrasion; expansion and contraction due to temperature changes; and, abrasion etc. due to visitors.

Water is the number one enemy of adobe and rammed earth buildings. Water is the original "plasticizer" and as such permits the shaping of clay. Once dried clay maintains its shape until it is rehydrated and returned to the plastic state. Rehydration may be the result of a single event or the continual wetting due to rain, dew, etc.

Water at Paquimé is mainly derived from rain. Torrential storms wash away any loose material leaving a new surface to be subjected to yet an other drying cycle.

Capillary action takes place in any porous material that finds itself in contact with another material with a higher percentage of liquid water. It must be remembered that the clays in the adobe provide a large area to store water and facilitate evaporation. In adobe walls in arid environments, the capillary action is re-enforced by the establishment of a vapour front which would seem to wick the water further up the walls, with a resultant increase in coving.

Paquimé is subjected to spring and early summer winds with peak velocities in excess of 17 m/sec (60 kph). The particles in the wind work like a sand blaster abrading the walls. The impact of these winds can be clearly seen in the asymmetrical wear of exposed walls. In general terms, the amount of material eroded from the western face of exposed north-south walls is more than twice that of the east face. This wind driven asymmetrical erosion is not found in protected walls.

The winds also help to wick out the moisture in the walls and increase the amount of damage attributed to "capillary action". The continual expansion and contraction due to temperature changes results in the chronic destruction of the most basic mechanical bonds. As previously noted ambient summer temperatures in the shade exceed 40°C while winter temperatures fall below -17°C. In the summer the temperatures of surfaces exposed to direct sun light will vary more than 40°C each day. This results in a small but not insignificant expansion and contraction cycle (Luis Torres, personal communication). In the winter the formation of ice crystals within the adobe also creates pressures that break the mechanical bonds.

Paquimé received over 17,500 visitors in 1989 and like the sand particles in the wind, they slowly but surely abrade whatever they touch. While it is hard to measure the impact of the individual visitor, the wear and tear can be easily detected month by month. The sucessful installation of a visitors trail has greatly reduced this damage.

Properly cared for adobe is a strong and long lasting material, but exposed to the elements it quickly melts and looses its structural properties. The individual and combined damage of water, wind abrasion, temperature changes and visitor induced abrasion are chronic and insidious since they take advantage of the weaknesses created by each other.

Conservation: In 1988 the National Institute of Anthropology and History, in collaboration with the government of the State of Chihuahua, undertook the restitution of Unit 6. Unit six is a single story rammed earth structure to the north west of the main living quarters. Unit six was previously restored by Eduardo Contreras in 1981.

The first step was to gather all the available documentary and photographic evidence that would facilitate the job. Based on Di Pesos' monumental work (Di Peso 1974; Di Peso, Rinaldo and Fenner 1974) a profile of each room was developed and converted into the work sheet used to evaluate each rooms' condition.

The second step was the application of sacrificial superficial layers of "new old adobe" that would cover and protect the original wall stubs. "New old adobe" is the material that was washed into the rooms as the buildings eroded and then was removed as fill during the excavation.

The wall stubs were scrapped to remove loose material, gently wetted down and covered with "new old mud". The "new old mud" was forcefully flicked on with a small mason's trowel. A 30 cm grid of yellow polypropylene strings and knots were placed within the first layer of the "new old mud". This grid will inescapably delineate the joint.

After the "new old mud" covered the old wall stub, the workman applied considerable pressure to create a smooth surface and float the fines to the surface. Then, indentations were made with the point of the trowel. These indentations helped stop cracks and improved the adhesion of the next layer. The workmen preferred to use their fingers.

When the first layer was quite dry, a second layer, and then a third, etc. were applied as necessary to bring the wall back to the dimensions specified in Di Pesos' reports.

An alternative approach is effective in some cases of advanced erosion. Walls were re-built using forms that simulated the original construction technique (Contreras 1985). These forms were positioned in the manner suggested by Contreras (1985) and filled with "new old mud". The forms were removed once the mud was dry enough to stand on its own. After each section was dry, the planks were raised and another section built. Once the wall was close to the dimensions specified (Di Peso, Rinaldo and Fenner 1974), one or more layers of mud were flicked on.

The use of forms is ideal only in specific situations. Forms are successful only in reconstructing walls from low stubs. Attempts to apply this technique to walls that have been heavily eroded laterally, but not vertically, have not met with success. As the new material dries, it tends to lose adherence and draw away from the old wall. There needs to be sufficient mass, at least 20 cm of "new wall", above the stub to bind the material applied to the sides.

Steps To Be Taken: The most important steps to be taken are the development of long term maintenance and protection programs. The success of a maintenance program depends on the financial commitment to semi-annual inspections that include both photographic and written documentation. Such semi-annual inspections are the key to site preservation since they provide the information needed to evaluate what techniques and actions have been successful as well as anticipate the budgetary needs in the short, medium and long term.

The protection program needs to addresess the different problems faced in protecting the different facets of the cultural heritage. Such a protection program needs to enlist the support of the general public, help them appreciate the pace that at which their history is being destroyed and create a conciencious force that strives to protect archives, historic buildings and archeological sites, etc.

The work done at one site has little meaning if everything else is forgotten. Steps must be undertaken to protect the plain as well as the dramatic. The general public pays for the protection of cultural resources and the public should know what it gets for its money. As government agencies we are no more than the custodians of the public interest. If there is no public interest, we are custodians of little more than a collection of anachronims.

Bibliography

Cetenal 1977
Climas Chihuahua, Instituto de Geografía, U.N.A.M., México, D.F.

Contreras Sánchez, Eduardo 1958
"Casas Grandes", thesis, Escuela Nacional de Antropología e Historia, México, D.F.

Contreras Sánchez, Eduardo 1985
"Antigua Ciudad de Casas Grandes, Chihuahua (Paquimé)", Cuaderno de Trabajo, núm. 1, Dirección de Monumentos Prehispanicos, I.N.A.H., Mexico D.F.

Cordoba, Diego A., Sherman a. Wengerd & John Shomaker, 1969
Guidebook of the Border Region, New Mexico Geological Society

Dean, Jeffrey S., and John C. Ravesloot, 1988
"The Chronology of Cultural Interaction in the Gran Chichimeca", Culture and Contact: Charles C. Di Peso's Gran Chichimeca, the Amerind Foundation, 2 - 7 October, 1988 Dragoon, Arizona

Di Peso, Charles Caradine 1960
"Recent Excavations at Casas Grandes (Chihuahua)",Katunob, 1(4);47-48

Di Peso, Charles Caradine 1965
"The Clovis Fluted Point from the Timmy Site, Northwest Chihuahua, Mexico", The Kiva, 31(2):83-87

Di Peso, Charles Caradine 1966
"Casas Grandes and the Gran Chichimeca", El Palacio, 75(4);45-61

Di Peso, Charles Caradine 1968
"Casas Grandes, a Fallen Trading Center of the Gran Chichimeca", Masterkey, 42(1);20-37

Di Peso, Charles Caradine 1974
Casas Grandes: A Fallen Trading Center of the Gran Chichimeca, Publication number 9, vols. 1-3. The Amerind Foundation, Inc., Dragoon, Arizona and Northland Press, Flagstaff, Arizona

Di Peso, Charles Caradine, John B. Rinaldo and Gloria Fenner, 1974
Casas Grandes: A Fallen Trading Center of the Gran Chichimeca, Publication number 9, vols. 4-8. The Amerind Foundation, Inc., Dragoon, Arizona and Northland Press, Flagstaff, Arizona

Judd, Neil M., 1977
"The Use of Adobe in Prehistoric Dwellings of the Southwest', Holmes Anniversary Volume, AMS Press, N. Y.

LeBlanc, Steven A., 1980
"The Dating of Casas Grandes", American Antiquity, 45( ):799-806

Lekson, Stephen H., 1984
"Dating Casas Grandes", The Kiva, 50 ( );55-60

Phillips, David A., 1989
"Prehistory of Chihuahua and Sonora, Mexico", Journal of World Prehistory, 3(4);373-400

Obregon, Baltasar de 1986
Historia de los descubrimientos antiguos y modernos de la Nueva España, Gobierno del Estado, Chihuahua, Chihuahua

Rathje, William, David A. Gregory and Fred Wiseman 1978
"Trade models and archaeological problems", Mesoamerican communication routes and cultural contacts, Thomas Lee and Carlos Navarrette, eds., New World Archaeological Foundation

Schmidt, Robert H, 1975
"The Climate of Chihuahua, Mexico", Technical Reports of the Meteorology and Climatology of Arid Regions, 23:50. Institute of Atmospheric Physics, University of Arizona, Tucson, Arizona

Schmidt, Robert H., 1983
"Climate and the Chihuahuan Desert", Natural Resources and Renewable Resources and Development in Arid Regions, (E. Campos & R. Anderson, eds.) pp.35-52. West View Press, Boulder, Colorado

FORT SELDEN RUINS CONSERVATION

Thomas J. Caperton
New Mexico State Monuments
Museum of New Mexico
Box 2087
Santa Fe, New Mexico 87503
U.S.A.

ABSTRACT

The mud and brick wall remnants at Fort Selden State Monument, New Mexico, U.S.A. were stabilized 1972, 1974, and 1985. The techniques employed included the placement of caps on wall tops, repair of basal erosion, establishment of drainage slopes to prevent the accumulation of water next to walls, preservation landscaping, and construction of visitor trails. These efforts have retarded, but not stopped, the deterioration of the site. It is suggested that research be directed toward the burial of cultural resources as a long-term preservation method, and it is recommended that sites should not be excavated and left exposed for purposes of public display and interpretation.

KEYWORDS

Preservation

Predictive Modeling

Resource Burial

Earthern Architecture

Display and Interpretation

Fort Selden, Administration Building, 1867. Photographic Archives: Museum of New Mexico.

Fort Selden, Company Quarters, 1867. Photographic Archives: Museum of New Mexico.

Fort Selden, Company Quarters and Post Hospital, 1886. Photographic Archives: Museum of New Mexico.

Location

Fort Selden is located in the semi-desert country of New Mexico in the southwestern United States, 85 km (53 mi) north of the Mexican border on the Rio Grande.

Historical Background

The post was established to protect visitors in the valley of the Rio Grande from Indian raids and bandits. The adobe fort was constructed in the late 1860s by soldiers from the garrison, military prisoners, and civilian employees.

The flat-roofed structures comprising Fort Selden were arranged about a rectangular parade ground, they included the Officer's Quarter's, Company Quarters, Administration Building, and the Post Hospital. Beyond the perimeter of the parade ground were the corrals, the Commanding Officer's Quarters, and the Trader's Store. Fort Selden was constructed to hold a complement of about 200 men.

According to military specifications the outer walls were .61 m (2 ft) thick and the inner walls, which did not support roof beams, were .30m (1 ft) thick. The outer walls had rock foundations and the interior walls had mud brick foundations. The walls were 3.05 m (10 ft) high from floor to ceiling with a .61 m (2 ft) parapet above the roof. The roofs consisted of peeled cottonwood logs (vigas) overlayed with small cottonwood poles (latillas) which were placed side by side. On top of these were a layer of willows placed crosswise, and on the willows a thick layer of hay and a 8.9 cm (3 1/2 in) layer of mud mixed with cut straw. On top of this was a layer of tamped dry earth and, finally, a 8.9 cm (3 1/2 in) layer of mud. Most of the exterior walls were not rendered, while the interior of the buildings were coated with a lime plaster.

There were continual problems with the upkeep of the mud brick buildings. During one period of particularly heavy rain, tents were pitched inside the rooms to protect the inmates and their possessions. In 1871 the Post Commander commented: "The buildings and quarters are sufficient for the present garrison, and have been well built from the material afforded by the country (adobe) but that material ... disintegrates so fast during the summer rains that constant repairs are needed to preserve the buildings for decay and ruin" (Cohrs, Caperton, 1983: 6).

The post was abandoned in 1891. The roofs, windows, and other salvageable material was reportedly given to a contractor in payment for removing the bodies from the post cemetery.

Environmental Data

Fort Selden is located at an elevation of 1126 m (3990 ft) above sea level. Temperature and precipitation has been recorded at a station 20.9 (13 mi) from the site since 1870.

The average annual maximum temperature (1870-1983) is 24.7° C (76.4° F), the average minimum temperature is 6.6° C (43.9° F). There are an average of 97 days a year with temperatures over 32.2° C (90° F) and 100 days with the temperatures at or below freezing. The mean annual precipitation is 21.60 CM (8.49 in). The rainy season is from July 1 to September 10. The months of July to September receive 54% of the annual rainfall.

Preservation Efforts

The former fort was acquired by the New Mexico State Monuments, a bureau of the Museum of New Mexico, in 1972. There is a visitor center with a full time staff at the site. Preservation projects were instituted at the monument in 1972, 1974, and 1985.

Walls Caps

During the historic occupation of the post, lime plaster was used to form a simple cap on the walls. Erosion problems at another nineteenth century fort in New Mexico were addressed by placing wide wooden planks on top of the walls to protect them and form a drip edge. The planks were held in place by additional mud bricks.

During the 1972 stablization effort at Fort Selden some of the wall remnants were capped with mud bricks which had been amended with a polyurethane resin (Pencapsula). The amended bricks were relatively impermeable and this may have resulted in the accelerated erosion of the wall fabric immediately below the cap. The bricks were laid in line with the walls with no drip edge. In some cases several courses of historic bricks were removed to form a base for the new material. The result of this work was a flat-topped unnatural appearance to the walls. The amount of original fabric removed would probably not have been lost from natural weathering processes for several decades.

Workman preparing eroded wall base for insertion of new adobe bricks, 1974. New Mexico State Monuments.

The amended bricks were removed in 1974 and the walls were coated with about 2.54 cm (1 in) of unamended mud to form a protective cap.

The walls were capped with unamended mud again in 1985. Narrow strips of red plastic sheeting were placed between the cap and original surface at 0.9 m (3 ft) intervals to act as indicators when additional maintenance work is required.

The unamended cap lasts about one year. The rapid deterioration of the cap is the result of the relatively wide wall surface which is exposed to rain and snow. Some of the walls which were not capped have eroded to a characteristic rounded or pointed top which tends to shed water and on which snow does not readily accumulate. While the unamended cap is an effective and aesthetically acceptable preservation technique, if well maintained, investigation should be made into the use of amendments that would retard erosion without having adverse effects upon other portions of the wall remnants. The use of shelters to protect the exposed mud brick walls might be a more effective preservation technique than capping. Careful consideration must be given to the design of the shelters so that they do not create adverse physical effects upon the wall remnants.

Workman contouring new adobe bricks to fit profile of historic wall, 1974. New Mexico State Monuments.

Wall Bases

Many of the wall bases at the monument exhibited typical basal erosion caused by rising damp, leaching of salts, wind carried abrasives, and to some extent, rodent infestation.

In 1974 the walls that exhibited advanced basal deterioration were repaired by inserting mud bricks into their base. The eroded areas were prepared by cutting them into a rectilinear form with a flat base to accept the new mud bricks which were set in unamended mud mortar. The square edges of the bricks were trimmed to match the contours of the historic walls.

Walls which exhibited less basal erosion were repaired with successive layers of mud plaster.

Adobe wall before stabilization, 1974. New Mexico State Monuments.

Drainage Slopes

Slopes were established to prevent the accumulation of water next to walls. The exterior and interior ground surfaces of the rooms were, as practicable, brought to the same level by lowering or raising the fill. This may prevent problems with the transference of moisture through the wall from the area of greater to lesser fill. The ground surface was then sloped away from the walls to facilitate water run off.

In those cases where there was severe and extensive basal erosion, earth berms were established against the walls to provide structural support. The berms were compacted and sloped away from the walls to prevent the accumulation of water next to them. The basal erosion pattern will reoccur at the juncture of the wall and top of the berm.

Drainage within room blocks was generally facilitated by channeling the water through doorways or gaps in the walls to the exterior of the structure. In cases where this was not possible, the interior of the rooms were contoured to encourage the puddling of water in the center where it would evaporate.

Adobe wall after stabilization, 1974. The ground surface has been raised to provide wall support and graded to facilitate water runoff. New Mexico State Monuments.

Preservation Landscaping

Several species of natives grasses that do not require watering after establishment were planted on the parade ground and the perimeters of the post. The grass may reduce the amount of wind carried particles that blast the wall remnants of the post during sandstorms. Vegetative growth is discouraged in the rooms for it is felt that it might retain moisture which would enter the walls.

Visitor Trails

Distinct trails were established through the fort and visitors are requested to stay on them. Them recudes impact on the walls from public use.

Predictive Modeling

In 1989 photographs from the occupational and post-occupational periods of the fort were compared with present-day photographs by Kevin McDougall and John

Preservation landscaping. Grass was planted on the parade ground to reduce the amount of wind carried abrasives. The trees replicate the historic landscape, 1985. New Mexico State Monuments.

Drainage contours to prevent accumulation of water next to walls. The grade is established to the center of this roadway. After snow, 1974. New Mexico State Monuments.

Officer's Quarters before stabilization, 1974. New Mexico State Monuments.

Officer's Quarters after stabilization, 1980. New Mexico State Monuments.

Jensen of the University of Queensland, Brisbane, Australia to dtermine if photogrammetry can be used to determine the erosion rate of cultural resources. McDougall and Jensen stated that it is possible to extract data from which the deterioration rate of adobe buildings could be determined. Predictive modeling possesses the potential to be an invaluable tool for both preservationist and site managers.

Resource Burial and Public Presentation of Cultural Resources

Low-lying walls at Fort Selden which were not of salient interest to visitors were draped with a soil membrane (geotextile) and covered with earth.

Resource burial is the most effective means of preservation known today. Sites should be recorded prior to burial and copies of the data placed in time capsules on the site. The resource could remain covered for generations and the time capsules might insure the survival of archival data. In cases where there are substantial above ground remains the resource should be covered to the greatest extent possible. Thus, a good portion of the site will remain relatively intact. Site burial has the additional benefit of discouraging vandalism.

The mud brick remains of Fort Selden are preserved by the State of New Mexico for purposes of display and interpretation. Such public programming can conflict with preservation efforts. Decisions regarding the presentation of the site may have a significant impact upon the cultural resource.

In many cases, extensive ruins in the southwestern United States which are open to public visitation have been stabilized in the same form that they were found after archaeological excavation. The resources did not exist in this condition, as a roofless ruin without room fill, during any period of their history. The walls, and other features, if left exposed, deteriorate rapidly. After several decades of weathering and/or repair the original fabric of the resource becomes enextricably altered. A fantasy historical environment may be created is this process continues. The preservation design ultimately may destroy the historic integrity of the resource.

Alternative forms of resource presentation and interpretation must be implemented. For example, sites can be effectively interpreted in a museum setting without sacrificing the integrity of the resource. Portions of a site might be excavated and enclosed in a structure with a controlled environment.

CONCLUSIONS

The preservation design of the mud brick wall remnants at Fort Selden, New Mexico included the placement of unammended mud caps on walls, filling of areas of basal erosion with mud bricks, establishment of drainage slopes to prevent the accumulation of water next to walls, preservation landscaping, construction of trails for site visitors, and resource burial. These techniques have, at best, extended the life expectancy of the ruins and hopefully have not had a deleterious effect upon the resource.

To date there is no panacea for the ills associated with the conservation of adobe cultural resources, and some procedures have resulted in their further degradation. The exploitive presentation of historic sites should be reconsidered in light of the fact that the original fabric of the resources is often sacrificed or lost for reasons of public programming.

The most effective preservation techniuqe for earthen ruins is burial. It is recommended that research be directed toward the burial of sites, alternative methods of presentation and interpretation, and the investigation of erosion rates.

REFERENCES

Caperton, Thomas J., Fort Selden Development Project Phase II. Project No. 35-73-0029. Museum of New Mexico, New Mexico State Monuments (Santa Fe: New Mexico, 1983).

Cohrs, Timothy and Caperton, Thomas J., Fort Selden, New Mexico (Santa Fe: New Mexico: Museum of New Mexico Press, 1974).

Gossett, William J. and Cye W., 1985 Stabilization Project, Fort Selden State Monument, Museum of New Mexico (Polvadera: New Mexico, Rio Abajo Archaeological Services, 1985).

McDougall, Kevin and Jensen, John, Photogrammetric Feasibility Study of Fort Selden for The Getty Conservation Institute, (Brisbane, Australia, The University of Queensland, 1989).

Stewart, Ronald L., Fort Selden Development Project, Phase I. Project No. 35-71-004. New Mexico State Monuments, Museum of New Mexico (Santa Fe: New Mexico, 1972).

ABSTRACT

In the "l'Ile district of Martigues (Bouches-du-Rhône - Southern France), important rescue archeological excavations have taken place during a twelve-year period (1978 - 1989) ; this work has shed much light on our knowledge of architecture and daily life in Southern Gaul during the Iron Age. Because of its exceptionally good state of preservation, the site has clearly demonstrated the importance of earthen materials in construction techniques and has provided a good insight into the domestic lay-outs within the two successive protohistoric villages found there.
In addition, this archeological work has led to a project aimed at presenting some of the earthen buildings of the first village, this through both restoration and reconstruction.

KEY WORDS

Archeology - Reconstruction - Earthen architecture - Domestic lay-outs - Earthen objects - Iron Age - "L'Ile" district of Martigues - France.

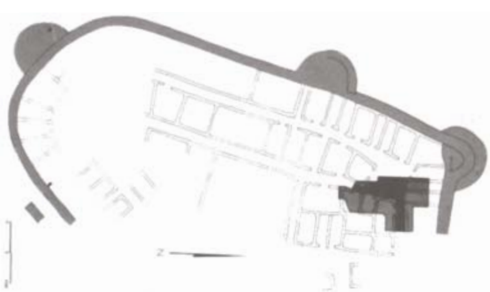


FIG. 1 Plan du premier village protohistorique (début Ve - début IIe s. av. J.C.) et implantation de la "Vitrine Archéologique". Dessin N. Nin.

FIG. 2 Fouille de l'espace concerné par la préservation archéologique. Place d'angle, rues et maisons du premier village. Photo Jean Chausserie-Laprée.

L'ILE DE MARTIGUES A L'AGE DU FER : UN VILLAGE EN TERRE

Histoire et préservation du site.

Jean CHAUSSERIE-LAPREE
Archéologue de la Ville de Martigues
Mairie de Martigues, BP 101
13692 MARTIGUES CEDEX - FRANCE

Introduction

De 1978 à 1989, le quartier de l'Ile à Martigues, petite ville de Provence Occidentale, a été le théâtre d'importantes fouilles archéologiques motivées par une opération de rénovation urbaine. Les principaux résultats de cette recherche concernent l'installation au début du 5ème siècle avant J.C. d'un habitat urbanisé qui est à l'origine de l'agglomération actuelle.

Entre le début du 5ème siècle et la fin du 2ème siècle avant J.C. deux bourgades protohistoriques se sont succédées au milieu du chenal qui relie l'Etang de Berre à la Méditerranée. Grâce à des conditions de sédimentation particulières -exhaussement du sol, submersion partielle, incendies répétés- les structures bâties des deux villages ont été remarquablement conservées. Elles offrent un large panorama des techniques architecturales et des pratiques domestiques en vigueur dans le Sud de la France durant l'Age du Fer, et soulignent l'importance de la terre crue dans la construction, l'aménagement intérieur, l'entretien et la décoration des maisons (1).
La qualité des vestiges qui a permis d'établir l'histoire des techniques architecturales protohistoriques utilisées sur ce site est à l'origine du projet de conservation et de mise en valeur de l'habitat in situ. Toutefois les problèmes liés au contexte urbain actuel, à la remontée de la nappe phréatique et à la nature des vestiges interdisaient une conservation en plein air. Le choix s'est donc porté sur une conservation en rez-de-chaussée de l'un des immeubles nouvellement construits. Ainsi derrière une "vitrine archéologique" est aujourd'hui présentée au public une partie du quartier nord-ouest du premier village gaulois. Huit habitations sont partiellement conservées et occupent, avec les trois rues et la place qui les desservent, une superficie de 70 M2 (voir fig. 1-3).

Un double parti de présentation a animé la réalisation de ce projet :

- la restauration des vestiges immobiliers dans leur état initial met clairement en évidence le plan d'urbanisme et l'architecture vernaculaire de cette agglomération. La superposition de murs d'époques successives trahit également le principe de sédimentation du site.

- la reconstitution intégrale de plusieurs maisons donne une image inédite de ce type d'habitat. La variété d'utilisation et l'adaptabilité du matériau terre trouvent ici une illustration que la seule conservation des murs n'aurait pu fournir.

On trouvera donc l'association des deux thèmes principaux traités dans cette conférence : l'histoire et la tradition de l'utilisation de la terre dans l'habitat d'une part, la restauration et la préservation des sites de l'autre.

TECHNOLOGIE PROTOHISTORIQUE DE L'ARCHITECTURE EN TERRE

Dans les deux villages l'architecture de terre se rencontre à tous les niveaux de la construction domestique (murs, toitures, sols, placages, aménagements intérieurs etc...) et se présente, en fonction de chaque utilisation, sous une forme et une technologie différentes.

LES MURS : LE PRINCIPE GENERAL DE CONSTRUCTION

Porteurs ou cloisons, les murs sont constitués de deux parties :
- une base en pierres liées au mortier de terre
- une élévation de terre crue

On trouve ici un modèle issu du monde hellénique et largement répandu sur les habitats protohistoriques du Sud de la France dès le début du 6ème siècle avant J.C. (2) (Voir fig. 4).

La base en pierres :
La fonction de la partie basse en pierres n'est pas identique selon qu'il s'agit de constructions initiales ou de reconstructions. Dans le premier cas la nature meuble du sous-sol rendait nécessaire une fondation enterrée destinée à protéger la base de la maçonnerie de l'affouillement. Quand le mur est rebâti sur une ancienne construction ruinée, la fondation devient un simple soubassement, à peine enterré, qui asseoit la partie en terre et l'isole des remontées capillaires d'humidité. La hauteur de ce socle, généralement peu importante (0,30 m à 0,50 m) peut atteindre 1 m sur certains murs de façade plus exposés aux chocs et à l'érosion (voir fig. 5).
Quelles que soient les périodes, la technique de construction est une maçonnerie porteuse à deux parements en moellons irréguliers montés en opus incertum et liés avec un mortier de terre.

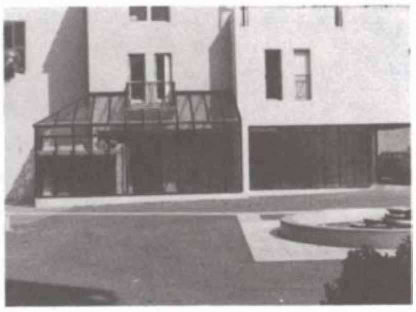


FIG. 3 Vue extérieure d'ensemble de la "Vitrine Archéologique". Photo J.C-L.

FIG. 4 Mur de fond d'une maison du premier village (IVème s. av. J.C.) Elévation d'adobes sur soubassement de pierres. Photo J.C-L.

FIG. 5 Fondation d'orthostates et soubassement de pierres d'un mur de façade du premier village (Vème - IVème s. av. J.C.) Photo J. C-L.

FIG. 6 Murs d'adobes effondrés dans une maison du premier village (IVème s. av. J.C.) Photo J.C-L.

FIG. 7 Mur associant briques crues et poteau central en bois (IIIème s. av. J.C.) Dessin N. Nin.

FIG. 8 Bouchage d'une porte selon la technique de la bauge (IIIe s. av. J.C.) Photo J.C -L.

Sa largeur moyenne (0,50 m) est un peu supérieure à celle de l'élévation en terre. L'arase supérieure des pierres est recouverte d'une chape de terre argileuse qui prépare le lit de pose des briques ou du pisé et assure adhérence et répartition égale des charges.

L'élévation en terre crue :
Une soixantaine de murs possédaient encore une élévation en terre en place. S'y ajoutent les nombreuses parois abattues dont l'analyse permet d'évaluer la hauteur des constructions. Celle-ci témoigne de l'inexistence d'étage que renforce l'absence de dispositifs spécifiques, telles les montées d'escaliers présents sur certains sites préromains ibériques ou provençaux (3) (voir fig. 6).
Trois modes principaux d'utilisation de la terre crue ont été mis en évidence : l'adobe, la bauge et le pisé. La documentation recueillie a précisé nos connaissances sur les périodes d'apparition de ces différentes techniques durant l'Age du Fer du Midi méridional. Elles ont aussi permis de saisir les modalités de mise en oeuvre de la terre et d'en tirer les enseignements pratiques pour l'opération de reconstitution.

L'adobe

La technique de l'adobe est la plus répandue. Présente dès la création de l'habitat, elle perdure jusqu'à sa destruction définitive.
Les briques sont obtenues par la mise en forme d'un mélange de terre, de stabilisant végétal et d'eau dans un moule rectangulaire. Malgré des déformations importantes dues aux oscillations de la nappe phréatique, aux tassements et à la mauvaise qualité des matériaux, une étude métrologique a pu être menée qui dénote la variété des longueurs des briques selon les périodes.
On constate aussi la grande disparité chromatique des adobes. Outre des sources d'approvisionnement diversifiées, ce phénomène témoigne de la réutilisation de terre à bâtir provenant de murs ruinés (4) (voir fig. 4 et 7).
L'appareil transparait grâce au mortier de liaison que distingue une couleur plus claire et une consistance très argileuse mal appropriée à la confortation des ouvrages. Il respecte généralement la règle de recouvrement des joints verticaux. Quelques constructions cependant laissent voir des coups de sabre responsables de graves malfaçons. Les maçonneries de briques révèlent aussi l'absence fréquente de liaison structurale des murs entre eux, qui trahit un rythme de construction original. Le premier mur édifié est le refend dont la longueur fixe l'alignement de façade et l'emplacement de la superficie de la maison peut-être en fonction de lots définis à l'avance. Ce procédé très rudimentaire tire sans doute son origine de la faible superficie des maisons, parfois dépourvues de façade (10 à 20 m2).

Trois murs porteurs en briques sur soubassement de pierres montrent l'association d'adobes et de poteaux en bois placés au centre de la maçonnerie (voir fig. 7). Cet appareillage mixte qui s'apparente aux constructions à pans de bois, est tout à fait original pour notre habitat et se distingue radicalement de la technique du torchis qui caractérise, dans le Sud de la France, des périodes plus anciennes et des zones moins influencées par les apports étrangers.

La bauge

Rare, la technique du façonnage direct et manuel de la terre touche des portions limitées de murs et paraît réservée à des situations architecturales particulières : bouchage d'une porte ou réfection d'une ancienne maçonnerie de briques. Son association aussi bien avec la pierre qu'avec l'adobe révèle sa liberté de modelage et sa facilité de mise en oeuvre (voir fig. 8).

En outre le matériau très composite de la bauge, riche en vestiges domestiques, indique un prélèvement et une préparation de la terre à bâtir dans l'habitat lui-même. Bien qu'occasionnelle, la bauge attestée dès le 4ème siècle avant J.C. semble préfigurer la technique du pisé qui se développe au 2ème siècle avant J.C.

Le pisé

Les murs massifs deviennent majoritaires dans le second village où ils apparaissent représentatifs d'une technique véritablement novatrice. Reposant sur un soubassement de pierres plus large (0,50 - 0,60 m) le matériau terre présente une coloration et une composition à peu près uniformes. C'est un mélange de sables, limons et argiles plus hétérométrique que les briques. Dans certains cas, des pierres dessinent des lignes horizontales interprétées comme des niveaux intermédiaires entre deux banchées de terre. Faute de vestiges attestant l'emploi de coffrage, ce sont les rares indices matériels d'utilisation du pisé. De plus la période d'apparition à Martigues de ce mode d'architecture correspond à son introduction sur d'autres sites méridionaux proches (Entremont, Marignane). Le pisé apparaît ici comme un transfert de technologie italique de même que la brique avait été empruntée au monde grec quelques siècles plus tôt (5) (voir fig. 9 et 10).

LES SUPERSTRUCTURES

C'est le domaine le moins bien connu puisque aucun élément s'y rattachant ne nous est parvenu en place. Encore avons-nous la chance que ce village ait subi trois incendies qui ont fossilisé des fragments de superstructures effondrées.


FIG. 9 Murs de façade en pisé du deuxième village (IIe s. av. J.C.) Photo J.C-L.


FIG. 10 Elévation en pisé d'un mur du deuxième village (IIe s. av. J.C.)

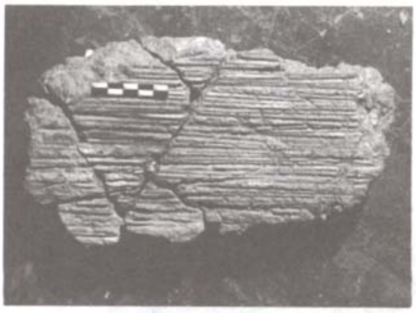


FIG. 11 Fragment de la couverture d'un toit-terrasse. Empreintes de roseaux sur la face inférieure. Photo G. Xuereb (Martigues Communication)


FIG. 12 Partie nord-ouest du premier village recouverte par la nappe phréatique. Photo J.C-L.


FIG. 13 Maçonnerie de pierres et de briques avant restauration. Superposition de deux murs successifs. Photo J.C-L.

Mais il est difficile de distinguer les vestiges de la toiture de ceux qui peuvent provenir d'un niveau intermédiaire. S'il parait acquis que cet habitat n'a pas comporté de maisons à étages, plusieurs observations nous incitent à restituer l'existence de mezzanines ou demi-plans partiels. D'abord l'exiguité des pièces que leur encombrement extrême rendait inutilisables sans le recours à un espace de vie supplémentaire. Mais également les nombreux objets retrouvés en position renversée dans les strates supérieures des couches de destruction, les poteaux implantés près des murs qui ne pouvaient servir de support à la toiture ou les planchers découverts carbonisés sur le sol.
De la toiture proprement dite, nous possédons assez d'éléments pour en restituer la composition et la forme. Obéissant à un modèle courant dans le Sud de la Gaule et en Espagne, elle est en terrasse et formée de deux parties : la charpente et la couverture.
La charpente, assemblée sans pièce métallique, se compose de solives de pin ou de chêne disposées dans le sens de la largeur et reposant directement sur le sommet des murs. Elles sont parfois relayées, au centre de la pièce, par une poutre principale seulement perçue grâce au trou ou à la base de poteau qui lui sert de support.
La couverture est faite d'un lit de roseaux arrangés à plat sur lequel est damée une couche de terre crue. Elle nous est connue par les nombreux fragments cuits accidentellement, offrant une face inférieure striée d'empreintes de végétaux, l'autre plane et lissée (voir fig. 11). Cette couche est un mélange de sables, argiles, graviers et fibres végétales, présentant les traces de multiples recharges, témoins d'un entretien permanent, qui finissent par former une épaisseur de terre allant jusqu'à 0,20 m, ce qui induit une charge importante de l'ordre de 300 à 500 kg/m2 (6).

LA VITRINE ARCHEOLOGIQUE : RESTAURATION ET RECONSTITUTION DE L'HABITAT

La présentation proposée dans la "vitrine archéologique" où sont préservées des structures d'habitat du premier village protohistorique, met en évidence, dans les élévations , la technique de l'adobe sur soubassement de pierres. La mise en oeuvre a eu recours aux techniques de construction originelles et respecte les principes architecturaux énoncés plus haut. Exclusivement manuelles, la préparation de la terre et la fabrication des briques ont été reproduites avec les moyens les plus simples. Un millier d'adobes aux modules en vigueur aux 4ème et 3ème siècles avant J.C. ont été réalisés dans des moules prismatiques en bois à compartiment simple. Par ailleurs la conduite, simultanément à ces travaux, d'une opération de fouille touchant le second village, nous a offert un approvisionnement en sédiments appropriés à nos besoins en matériau.
Enfin, pour éviter, dans l'architecture, tout désordre lié à la présence de la nappe phréatique sous-jacente (voir fig. 12), nous avons enterré avec du sable les structures les plus profondes et protégé les vestiges par un système d'étanchéité et de drainage adéquat (chape de béton et feuille de plastique) (7).

LA RESTAURATION

Dans la moitié sud du local où les vestiges archéologiques sont présentés dans leur caractère originel, l'état de dégradation des maçonneries a rendu indispensable une reconstruction des éléments qui avaient souffert des intempéries durant la fouille et des travaux d'édification de l'immeuble contemporain.

Après relevé et démontage, les structures ont été rebâties soit avec leurs matériaux propres quand ils pouvaient être réutilisés (pierres) soit avec un matériau similaire dans le cas des briques, du liant et des enduits. Les parties reconstruites ne l'ont pas été exactement à l'identique, les murs montrant souvent des pathologies structurales récentes sans rapport avec la réalité archéologique. Ainsi avons-nous décidé de restituer l'état des maçonneries au moment de leur découverte en mettant en valeur les phases de construction successives (voir fig. 13 et 14).
A cause des contraintes techniques les murs restaurés ne représentent que les dernières périodes d'occupation du village primitif. Ils montrent le remontage de la maçonnerie de pierres la plus récente (fin 3ème siècle avant J.C.) sur la portion conservée de l'élévation en adobes du mur antérieur (milieu 4ème - milieu 3ème siècle). Par souci pédagogique ils sont dénués d'enduit protecteur. Une attention particulière a été portée sur les joints qui révèlent l'appareil. Toutes les fissures de retrait intervenues après la pose du mortier ont été bouchées et la surface des joints lissée.

LA RESTITUTION

A l'extrémité nord du local, les vestiges protohistoriques n'avaient pas la même qualité architecturale, les travaux de fondation de l'immeuble moderne ayant endommagé les murs en élévation.
Nous avons donc entrepris de les rebâtir entièrement et de recomposer cette partie du village à partir des données de fouilles ou de références ethnographiques.
La présence d'un pilier d'angle du bâtiment actuel a interdit de respecter exactement le plan-masse des maisons. L'exiguité des espaces intérieurs exposés nécessitait de modifier légèrement l'implantation primitive des maisons pour masquer cette intrusion contemporaine en l'englobant dans un mur de refend (voir fig. 15 et 16).

FIG. 14 La même maçonnerie après restauration. Photo J.C-L.

FIG. 15 Stockage des adobes en vue de la reconstitution de l'îlot nord. Photo J.C-L.

FIG. 16 Masquage par le mur de briques crues d'un pilier d'angle en béton de la "Vitrine Archéologique". Photo J.C-L.

FIG. 17 Elévations et superstructures reconstituées de 4 maisons du premier village gaulois de l'Ile de Martigues. Photo J.C-L.

FIG. 18 Elévations de briques crues sur soubassement de pierres. Parements dénués de revêtement. Photo J.C-L.

Au total cinq habitations ont été partiellement reconstituées. Situées de part et d'autre d'une ruelle et donnant sur la placette d'angle, elles composent un petit ensemble qui recrée l'image urbaine de cette agglomération protohistorique (voir fig. 17).

Murs, sols et enduits

Dans la continuité des vestiges de la partie sud du local, la maison d'angle est dépourvue d'enduit extérieur. Au-dessus du soubassement originel en pierres restauré, l'élévation restituée montre un appareil soigné d'adobes maçonnées avec un mortier argileux selon la règle de recouvrement des joints verticaux. La façade donnant sur la place a été percée d'une petite fenêtre dont la présence répond à une triple motivation : donner une prise de lumière à l'ouest, permettre une meilleure intégration de la maison au dispositif urbain de la place et démontrer, notamment par l'absence de linteau, la résistance mécanique de la terre crue quand elle est correctement mise en oeuvre (voir fig.18).

A l'inverse, les élévations des maisons qui forment la façade nord de la ruelle sont enduites intérieurement et extérieurement, conformément aux observations de terrain. A l'intérieur, ces revêtements ont un rôle autant fonctionnel qu'esthétique. Fréquemment restaurés, ils présentent, pour un même niveau d'occupation, jusqu'à trois ou quatre recharges correspondant aux réfections du sol avec lequel ils viennent se confondre. Cette accumulation masque les différentes épaisseurs du mur. Très fins et appliqués en surface sous forme de badigeon, ils concourent à éclaircir les pièces. Incontestablement ces revêtements participent à l'embellissement de l'espace intérieur de la maison dont ils suppriment les angles vifs (8) (voir fig. 19).
A l'extérieur, les enduits étaient plus dégradés du fait de leur exposition aux intempéries et aux chocs. Le projet de reconstitution insiste sur cet aspect par une composition différente et une apparence moins homogène qui atteste leur usure (voir fig. 20).
Nous fondant sur des témoignages anciens et actuels nous avons renforcé cet enduit de fibres végétales qui améliorent sa résistance à l'érosion. Un badigeon fin de terre argileuse lissée l'imperméabilise (9) (voir fig. 21).

La mise en oeuvre des briques a respecté les principes architecturaux antiques même quand ils ne répondaient pas à une construction dans les normes. Seule une maison a vu son angle nord-ouest édifié selon les règles strictes de l'appareillage d'angle avec un chaînage régulier de briques, par mesure de sécurité. Partout ailleurs il n'y a pas de liaison structurale des murs de refend avec les murs de façade qui viennent s'appuyer contre eux. Cette absence de chaînage est encore aggravée, dans l'îlot nord, par le percement de nombreuses portes que la taille des maisons contraint presque toujours à placer près d'un angle malgré les risques de flambement du trumeau ou du mur de refend lui-même que cela comporte (voir fig. 22 et 23).

Niches, étagères et banquettes

Certains dispositifs ont été introduits pour pallier les problèmes de rangement du petit mobilier qui abonde dans chaque maison. Il s'agit d'étagères constituées d'une planche appuyée sur des piquets de bois fichés dans la maçonnerie, de niches réservées dans l'épaisseur du mur, dont les formes et les dispositions ont été empruntées à des exemples actuels du pourtour méditerranéen (10). Ces aménagements permettent de disposer les objets qui ne trouvent pas au sol de place appropriée (voir fig. 24).
Ils trouvent un complément dans les banquettes basses qui courent sur le sol le long des murs. Faites d'une rangée de briques crues maçonnées sur une ou deux assises, elles sont solidaires du mur et du sol par l'enduit argileux qui les recouvre.
Dans un espace domestique multifonctionnel, leur rôle a pu être divers : étagères basses permettant d'isoler du sol des réserves alimentaires, tables de travail pour la préparation des repas, supports d'objets fragiles ou encore banquettes pour s'asseoir (voir fig. 25).

Les superstructures

Ne disposant d'aucun espace intérieur complet nous avons opéré ici de façon didactique, sélectionnant pour chacun d'eux un type d'aménagement. Ainsi pour l'habitation vue en coupe à l'angle nord-ouest de la vitrine, on a privilégié l'hypothèse d'un demi-plan restreint servant de support à deux grands silos en torchis. Ancré dans le mur et soutenu au sol par un poteau d'angle, il est constitué d'un plancher en pin recouvert de quelques centimètres de terre (voir fig. 26). La deuxième maison est dotée d'une mezzanine couvrant toute la largeur de la pièce. Zone de stockage pour des vases à provision et lieu de repos, ce niveau intermédiaire, soumis à de plus lourdes charges, a nécessité le recours à des bois plus importants. Il s'accompagne d'un système d'accès composé de pièces de bois plantées en escalier dans le mur (voir fig. 19 et 27).

La reconstitution des toitures a également tenu compte d'autres observations de terrain : absence de terre effondrée au pied des murs, stockage de matériel domestique en terrasse qui suppose l'existence, au-dessus des murs, de rebords de toiture hauts de 0,10 à 0,20 m permettant de retenir la terre, de mieux contrôler l'évacuation de l'eau avec des gargouilles et de servir de protection pour les gens et le mobilier.

FIG. 19 Espace intérieur d'une maison reconstituée. Badigeon d'argile blanche et aménagements domestiques. Photo G. Xuereb (Martigues Communication).

FIG. 20 Façade de l'îlot nord reconstitué. Parement revêtu d'un enduit de terre argileuse. Photo G. Xuereb (Martigues Communication).

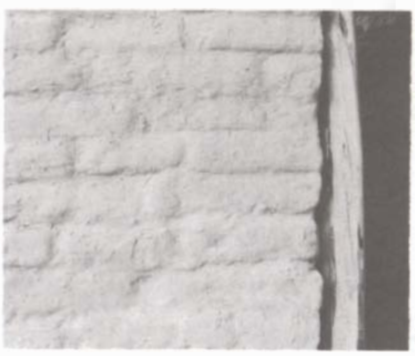


FIG. 21 Détail d'un enduit extérieur renforcé de végétaux. Photo J.C-L.

Ils jouent aussi un rôle esthétique rendu ici par les différences de niveaux entre les toitures et les acrotères d'angle. Bâtis en terre façonnée, ils devaient être régulièrement restaurés par suite de l'érosion et du ruissellement. Le badigeon de couleur claire appliqué en surface, en augmentant la réflexion solaire, contribue à une meilleure isolation thermique des toitures (voir fig. 27).

Le mobilier en torchis

Omniprésente dans l'architecture, la terre crue est aussi un élément essentiel de la vie quotidienne à travers un type de mobilier qui envahit littéralement l'espace domestique, à savoir les récipients et objets en torchis. Préservés grâce aux incendies qui les ont fossilisés, ils constituent, à Martigues, un répertoire unique pour tout le bassin méditerranéen protohistorique (voir fig. 28).

La matière qui les compose est un mélange d'argile et de végétaux auquel devaient sans doute être ajoutés des excréments animaux si l'on se réfère aux exemples actuels. Leur montage se fait par tranche de 7 à 10 cm et le modelé qui reste souvent apparent, frappe par la liberté des formes et la variété des combinaisons (11).

Ce mobilier recouvre deux fonctions principales : le stockage des provisions et la cuisson des aliments.

On trouve d'abord des silos ou vases de réserve pour les céréales, fruits séchés etc... Grandes jarres cylindriques, carrées ou rectangulaires, récipients bas en forme de jatte droite ou carénée, ils sont montés à l'intérieur de la maison, à leur emplacement définitif et reposent sur un socle isolant de pierres ou d'adobes ou sur une étagère qui les protége des prédateurs et de l'humidité (voir fig. 26).

Outre ces vaisseaux solidaires du sol ou de leur support, de nombreux autres vases en torchis, mobiles pour la plupart, complètent en les diversifiant les modes de conservation des denrées alimentaires. Il est enfin un autre élément, essentiel, fabriqué en terre crue : le four, composé de quatre parties indépendantes dont l'assemblage aboutit à un objet complexe. Placé près de la porte et lié à une plaque à feu, il diffère des fours en dôme traditionnels qui servent à cuire les galettes par une utilisation sans doute multifonctionnelle, pouvant répondre aux principaux besoins culinaires : cuisson des mets bouillis et du pain, boucanage des viandes et poissons, torréfaction des céréales (voir fig. 29,30 et 31).

Enfin comme matériau de base, la terre crue est présente au sein même de l'unité domestique à travers les couronnes de torchis, stockées en pile, qui constituaient probablement des pains d'argile prête à l'emploi pour la fabrication ou la réfection de ces objets (voir fig. 32).

Conclusion

La préservation des vestiges d'habitat en terre, mise en oeuvre dans la "vitrine archéologique", a tenté de concilier réalité archéologique et intérêt muséographique. Adapté aux contraintes techniques du site, le programme réalisé a voulu rendre compte de ces deux aspects distincts en proposant d'une part la restauration sur place des bâtiments tels qu'ils nous étaient parvenus, d'autre part la reconstruction de plusieurs maisons afin de tenter de redonner une apparence originelle et vivante de ce fragment d'agglomération gauloise. Avec cette première expérience menée dans le Sud de la France une attention particulière a été portée sur la présentation des modèles architecturaux originaux encore peu ancrés dans l'imagination collective où la terre crue, sous des formes multiples, joue une rôle fondamental.

FIG. 22 Construction d'un mur de refend sans chaînage avec la façade. Photo G. Xuereb (Martigues Communication).

FIG. 23 Le même ensemble une fois édifié et recouvert d'enduit. Photo J.C-L.

FIG. 24 Niches et étagères murales dans une maison reconstituée. Photo G. Xuereb (Martigues Communication).

FIG. 25 Banquette basse en terre dans une maison du second village (IIe s. av. J.C.) Photo J.C-L.

FIG. 26 Demi-plan restreint servant de support à des silos en torchis. Photo J.C-L.

FIG. 27 Vue extérieure en coupe de deux maisons reconstituées. Toits terrasses et mezzanines. Photo J.C-L.

NOTES ET REFERENCES

(1) J. Chausserie-Laprée, N. Nin et L. Domallain, "Le village protohistorique du quartier de l'Ile à Martigues (B.D.R.). Urbanisme et architecture de la phase primitive (Vème - IIIème siècles avant J.C.). 1. Urbanisme et fortification", Documents d'Archéologie Méridionale 7 (1984) : pp27- 52.

J. Chausserie-Laprée, N. Nin, "Le village protohistorique du quartier de l'Ile à Martigues (B.D.R.). Urbanisme et architecture de la phase primitive (Ve - IIIe siècle avant J.C). 2. Les données nouvelles sur l'urbanisme et architecture domestique". Documents d'Archéologie Méridionale 10 (1987) : pp 31 - 89.

Le Village gaulois de Martigues, Dossiers Histoire d'Archéologie, n° 128, Juin 1988, 98 p.

(2) A. Nickels, " Les maisons à abside d'époque grecque archaïque de la Monédiaire à Bessan, Hérault ". Gallia. 34.1. (1976) pp 95 - 128.

P. Arcelin et O. Buchsenschutz, " Les données de la Protohistoire " dans Architectures de terre et de bois, Documents d'Archéologie Française. 2. (1985) pp 15 - 28.

(3) H. Bonet et I. Pastor, " Technicas constructivas y organizacion del habitat en el poblado iberico del Puntal dels Llops (Olocau Valencia) ". Saguntum. 18 (1984) pp 163 - 187.

H. Bonet et P. Guerin, "Techniques de construction et aménagement des espaces domestiques ibériques en région valencienne". dans Habitats et Structures domestiques en Méditerranée occidentale durant la Protohistoire. Préactes du colloque international d'Arles (19 - 21 oct. 1989) pp 128 - 132.

P. Arcelin, "L'habitat d'Entremont. Urbanisme et modes architecturaux". dans Archéologie d'Entremont. Catalogue du musée Granet (Aix-en-Provence 1987) pp 57 - 98.

(4) Pour une étude sédimentologique et granulométrique du matériau terre sur des habitats protohistoriques méridionaux, voir l'étude de Philippe Boissinot dans " Le village protohistorique du quartier de l'Ile à Martigues ". Documents d'Archéologie Méridionale, 10 (1987) pp 66 - 68. Voir aussi :

Ph. Boissinot, "Les constructions en terre au IIème siècle avant J.C. sur l'oppidum du Baou Roux (Bouc-Bel-Air, B.D.Rh.)," Documents d'Archéologie Méridionale, 7 (1984) pp 79 - 96.

P. Poupet et C.A. de Chazelles, "Analyses archéologiques et sédimentologiques des matériaux de terre crue de l'architecture protohistorique de Lattes, provenance et technologie", Lattara, 2 (1989) pp 11 - 32.

(5) P. Arcelin et O. Buchsenschutz, "Les données de la protohistoire" p 23.

(6) H. Houben et H. Guillaud, "Traité de construction en terre", Craterre (Marseille, éd. Parenthèses, 1989) p 276.

K. Huet et T. Lamazou, " Sous les toits de terre, Haut Atlas " (éd. Publi-Action, 1988) p 26 - 29.

(7) H. Houben et H. Guillaud, " Traité de construction en terre ", p 296 - 297.

(8) L'emploi de pigments naturels minéraux et végétaux comme décoration a dû être utilisé si l'on se réfère à des exemples antiques (Lattes, Baux de Provence, Glanum, sites ibériques) ou actuels (maisons de Kabylie)

- P. Poupet et C.A. de Chazelles, "Analyses archéologiques des matériaux de terre crue" p 27 - 28.
- P. Arcelin et O. Buchsenschutz, " Les données de la protohistoïre" p 24.
- M. Abouda, " Maisons Kabyles : espaces et fresques murales". éd. AXXAM (1985), 108 p.

(9) " Dictionnaire illustré multilingue de l'architecture du proche orient ancien " sous la direction de O. Aurenche, (Ed. Maison de l'Orient, 1977) pp 80 - 81.

(10) J. Dethier, " Architectures de terre ", (Ed. du Centre Pompidou, Paris 1986, p 92.

FIG. 28 Mobilier en torchis (silos rectangulaires, couvercles, jattes etc...) dans une maison incendiée du 1er village (IVe s.av. J.C.) Photo J.C-L.

FIG. 29 Four complexe en torchis effondré à l'angle d'une maison incendiée du premier village gaulois (IVème s. av. J.C.) Photo J.C-L.

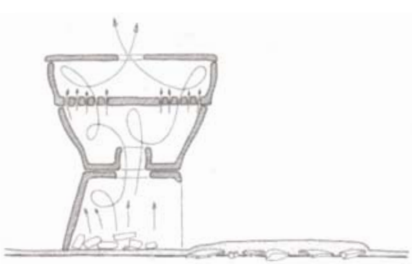


FIG. 30 Dessin schématique du four complexe. Dessin L. Domallain.

FIG. 31 Reconstitution du four en torchis. Photo J.C-L.

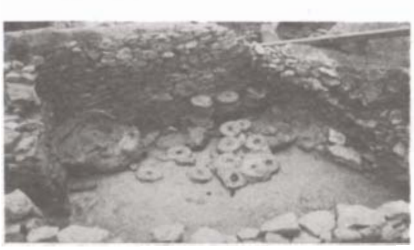


FIG. 32 Couronnes d'argile disposées à l'angle d'une maison du premier village gaulois (IVe s. av. J.C.) Photo G. Xuereb (Martigues

(11) G. Castel, " Une habitation rurale égyptienne et ses transformations " dans Nomades et Sédentaires, perspectives ethnoarchéologiques, éd. Recherches sur les Civilisations, mémoire n° 40 (Paris, 1984) pp 123 - 189.

H. Camps Fabrer, Article A 151 : " AKUFI " dans Encyclopédie Berbère III, éd. Edisud (1986) pp 428 - 431.

M. Abouda, " Maisons Kabyles : espaces et fresques murales " 108 p.

THE SLUMPING OF THE GREAT KNOB: AN ARCHAEOLOGICAL AND GEOTECHNIC CASE STUDY OF THE STABILITY OF A GREAT EARTHEN MOUND

Thomas E. Emerson
Illinois Historic Preservation Agency
Old State Capitol
Springfield, Illinois 62701

William I. Woods
Department of Geography and Earth Science
Southern Illinois University at Edwardsville
Edwardsville, Illinois 62026

ABSTRACT

Monks Mound or the "Great Knob"--located at the prehistoric site of Cahokia in Illinois, across the Mississippi River from St. Louis--is the largest earthen mound north of Mexico. After centuries of stability several major slumping episodes have occurred at the Great Knob in the last five years. Archaeological and geotechnical investigations have indicated that the mound was structurally engineered to resist internal slumping but that recent shifts in groundwater levels have damaged the internal structure leading to instability. Numerous engineering solutions for stabilization were examined but all were found to impact severely the visual, archaeological, or architectural integrity of the mound. In the final evaluation it was determined that passive management was the best current approach.

KEYWORDS:

Archaeology, prehistoric earthen mound, stabilization, passive management, drainage

Introduction

About one thousand years ago, the aboriginal peoples of southwestern Illinois reached their cultural climax and greatest elaboration with the rise of the Middle Mississippian culture. This period saw the development of temple mound centers, hierarchical political and religious organization, large-scale trade, and full-time agricultural subsistence patterns. One of these temple mound centers and its society far exceeded the rest in size and complexity. This is the site of Cahokia, located just across the Mississippi River from St. Louis, Missouri, in the expansive American Bottom floodplain of Illinois (see fig. 1).

Cahokia's size is impressive--the habitation and ceremonial areas are thought to cover at least 13 km2 and include over one hundred and twenty mounds (see fig. 2). Dominating the site is the Great Knob or Monks Mound, a large, multiterraced platform mound (see fig. 3) located within the central ceremonial precinct. This structure holds the distinction of being the largest earthen mound north of Mexico. It measures about 291 m north-south, 236 m east-west, and 33 m in height [1].

Today, about 7,500 ha of the site, including the central ceremonial precinct and many of the mounds, are owned by the State of Illinois and managed by the Illinois Historic Preservation Agency (IHPA). The Cahokia Mounds Historic Site is listed on the National Register of Historic Places, is a National Historic Landmark, and is on the World Heritage List.

The Great Knob Slump

Since its first depiction in the early nineteenth century, Monks Mound has sustained only slight surficial modification due to direct human alterations and sheet, rill, and gully erosion. In the mid-1950s, and again in the late 1960s, two minor slope failures took place. The effects of these were readily patched and none of the movements were viewed as seriously endangering the mound as an architectural monument. However, in February 1984 a moderate slope failure along the eastern mound edge called into question the future stability of Monks Mound. The State began joint archaeological [2] and geotechnic [3] studies of this east face slump. Virtually while this work was in progress, in April 1984, a massive slope failure occurred on the western face (see fig. 4). This slump was larger than all previously known examples and over the subsequent few months showed no signs of naturally stabilizing as the other slumps had done.

At this point, there was intense pressure from both State and Federal organizations to make immediate emergency repairs to the slump areas. Fortunately, we were able to argue convincingly that so little was known about the internal structure of the mound or the causes of the slope failures that it would be premature to undertake any emergency actions until more information could be gathered.

Research and Philosophy

At that point, the IHPA expanded its research to address the entire issue of mound slumping. This research had three immediate goals: (1) to determine the cause of the current slope failure; (2) to design a way to arrest this process; and, (3) to evaluate the impact of these actions on the architectural and archaeological integrity of the monument. The geotechnical aspect of the study was performed by Mathes Geotechnical Services, Inc. [4] and was a continuance of their earlier work on the east slump. The archaeological portion of the study was conducted by the Contract Archaeology Program, Southern Illinois University at Edwardsville (SIUE) and focused on the compilation and synthesis of all previous historical and archaeological information available on the Great Knob [5], as well as a limited program of test excavation and mapping on the west slump [6].

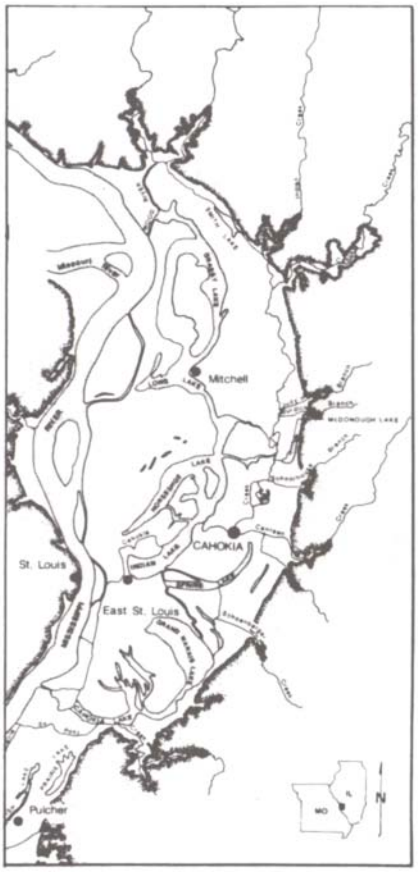


Fig. 1 - Map of the American Bottom showing the locations of Cahokia and the major Mississippian mound groups.

As these studies went forward, a parallel process was undertaken to assess the philosophical and ethical implications of any proposed stabilization and restoration effort. In May 1985, the IHPA convened a working meeting including international, national, and regional experts on resource management as well as leading scholars on Cahokia research to discuss the issues of restoration, stabilization, investigative excavations, and public interpretation. There was strong unanimity that stabilization rather than restoration was the goal. However, there was a basic dichotomy in the participants' approaches to the treatment of the Great Knob. These differences resulted from each individual's perception of the mound as primarily an "architectural monument," a "database," or a "public interpretive resource." Those perceiving the mound as architecture strongly urged the construction of a large surrounding berm to preserve its form. Researchers focusing on the informational aspect suggested excavations to retrieve information that might be lost during the slumping process. Those responsible for interpreting the site to the public were concerned about any approach, e.g., massive berming, that drastically modified the visual fabric of the mound and surrounding area. Out of this diversity of opinions, the discussants argued for a solution that preserved the Great Knob's visual and architectural integrity, minimized the loss of archaeological information, and was long-term in nature.

Background

The Great Knob is underlaid by natural submound deposits that are associated with a relict channel bar complex of the Mississippi River, as well as more recent slackwater sediments and overbank deposits of Cahokia Creek, the major drainage in the American Bottom. Although matrix textures of these materials are predominantly sands, loamy silts and clays are also present, particularly in near-surface positions. These natural deposits are superimposed by premound anthropogenic accretions of varying thickness.

It is hypothesized that construction began during the late Emergent Mississippian period (A.D. 950) with the bulk of the present mound completed by the end of the initial phase of the Mississippian period (A.D. 1050). This would include the vast majority of the fill to the north of the so-called first terrace. Subsequent additions continued throughout much of the Mississippian period until ca. A.D. 1250 or earlier. These additions consisted of a sequence of veneer caps on the third and fourth terraces, completion of the first terrace, and also of secondary mounds on the southeastern corner of the third terrace and the western end of the first terrace [7]. Elite buildings, free-standing walls, and large posts have been identified through excavation [8-11]. They are associated with the uppermost planar surfaces. Toward the end of the Mississippian period a domestic structure was present on the first terrace secondary mound with refuse distributed around its periphery, indicating the greatly diminished ceremonial status of the facility [12].

A number of coring and excavation projects have demonstrated that the mound is composed entirely of readily available earthen materials [13-21]. Furthermore, it is evident that there were decisions made as to the selection

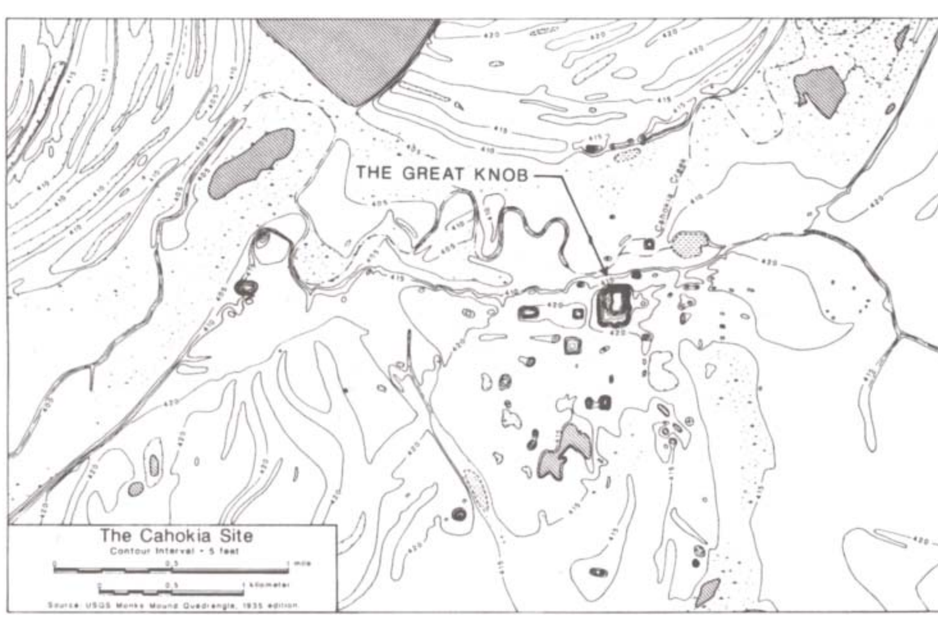


Fig. 2 - The location of the Great Knob within the Cahokia Site.

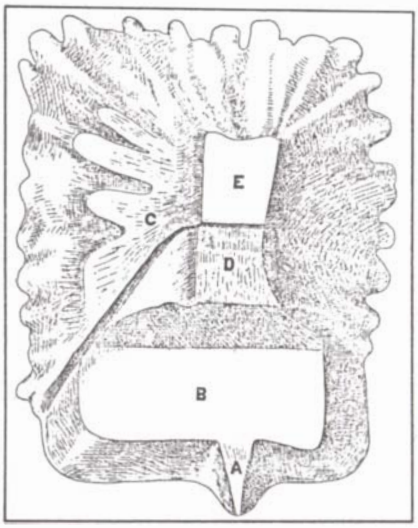


Fig. 3 - Late nineteenth century depiction of the Great Knob.

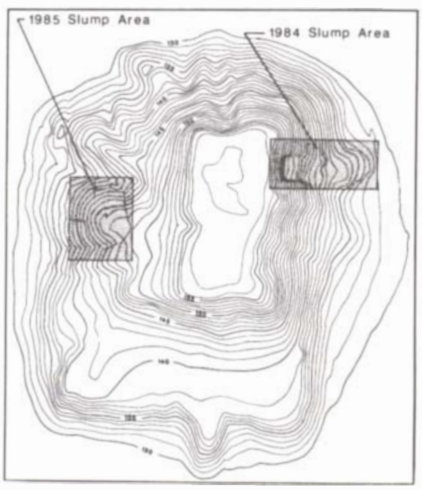


Fig. 4 - Topographic map of the Great Knob with slumps indicated.

and placement of materials within the mound. Indeed, far from being just a pile of dirt, the Great Knob was constructed with mechanical and engineering considerations in mind; in other words, detailed planning was used. Internally, a series of massive silty-clay to clayey-silt fill units were emplaced, with upper surfaces sloping to the exterior. In most cases these were covered with coarser materials that would have functioned as internal drains to remove atmospheric water before infiltration into the core sediments. Puddled clay facings may also have been present to facilitate runoff. Retaining buttresses were incorporated into the internal structure of the mound, as well as being emplaced externally along the southern and western peripheries [22-24].

The efforts expended on engineering suggest an understanding of the problems inherent in earthen constructions of this magnitude in humid, mid-latitude climatic regimes. The basic problem concerns the materials themselves. A significant portion of the mound mass is composed of smectite clays with a high shrink-swell capacity and low hydraulic conductivity. When wet, these clays displace more volume than in the dry condition, while they contract and tend to crack upon drying. The consequences of repeated episodes of drying and wetting are obvious: They produce great instability. Given a high local water table and an annual average of over 65,000 m3 of precipitation on the surface of the mound, continual water control was essential for maintenance.

The degree of success of the prehistoric engineering can be measured by the long-term stability of the mound. With the exception of the prehistoric slumping evidenced by the two east lobes on a side where no buttressing was present, for a millennium no major failures occurred in spite of the instability of materials and enormous mass and surface area of structure. The question is why is it failing now?

In the judgement of the authors, the most likely scenario suggests that the rapid sequence of recent failures is associated with modern changes in groundwater levels. From the 1940s to the early 1960s, water use by local industries was of such a magnitude that groundwater tables in the entire northern portion of the American Bottom were lowered drastically to the point where many wells went dry. By the late 1960s, water tables began to rise again due to recycling and industrial closings and within a decade were approaching their former levels. In response to the initial dropping of the water table, the lower core of the mound dried out for the first time, where previously it had been wetted by capillary action to a height of up to 10 m. Consequently, this portion of the core contracted and probably developed cracks at numerous locations. This shrinking of the core would also have disrupted the integrity of higher parts of the construction, including the drains and massive fill units. The expansion of the core due to rewetting exacerbated this problem. With the internal drains no longer functioning efficiently and cracks in the clay core, massive fill units, and clay caps, intrusion and retention of atmospheric water increased dramatically. As a result of this instability, failure and slumping occurred. The prehistoric planning that had been successful for centuries had not taken into consideration modern changes in the water table.

Proposed Stabilization Remedies

Analysis of the geotechnical engineering data indicated three areas in which action could be taken to stabilize the current mound configuration: (1) reduce the internal seepage pressures; (2) modify the mound geometry; and/or, (3) mechanically restrain the slope [25]. Having established the broader parameters within which to frame a specific remedy to the slope failures, more detailed methods of intervention were investigated for possible use [26]. Each of these methods incorporated one or more of the three stabilization principles noted above.

A number of solutions were based on the concept of "toe-loading" of the slump in which weight is physically added to the outward end of the slope to resist movement. These methods varied from a complex benching program to simple toe-loading. Benching the mound would begin with the addition of fill to create a base berm at least 15 m in width. Sloping fill would be added to form the base for another berm higher up slope and so forth up the mound sides. A granular drainage blanket would be placed under the fill to ensure drainage. A variation on this program would simply add fill to the mound surface to lessen the angle of the face thus creating a flattened, more stable, slope. While having a high success potential, these solutions would create a severe impact on the mound's visual appearance. A modified version of these techniques would simply be the addition of a toe-berm, about 15 m wide and 6 m high, around the base of the mound. While the visual effect would be lessened, it would leave the upper parts of the mound subject to localized slumping.

Other proposed methods of restraining the movement of the mound base involved the construction of retaining walls. Tied-back retaining walls are held in place by anchors drilled back into the mound, while a more conventional wall would be dug into the ground around the base. Both types would require the addition of fill to protect the upper mound slopes, impede already poor drainage, and involve a great disturbance of archaeological village deposits around the mound as well as of the mound matrix. The visual impact of retaining walls, however, could be kept to a minimal level.

Mechanical restraint of the slope could also be achieved by physically "nailing" the mound matrix in place or by replacement of some matrix. This could be done by driving or drilling pilings or piers through areas of slope failure or potential failure. Such structural features could range from ca. 1-m-wide crushed stone columns to 5-cm cylindrical rods or angle iron. A more drastic measure would be to excavate and remove large portions of the lower mound fill and replace it with crushed rock, both to strengthen the structure and assist in drainage. The advantage of nailing or matrix replacement techniques is that they have no visual impact on the mound and some, such as those including crushed stone, also facilitate internal drainage. Yet the internal damage to the archaeological integrity of the mound would be severe in most instances.

From the inception of the slope failures it had been clear that the primary source of the problem was water saturation of the mound matrix. A number of proposed solutions thus incorporated water removal techniques as either a primary or secondary aspect of their program. Primary drainage techniques included the use of dewatering well points, interceptor trenches and drains, stone trenches, horizontal drainage tunnels or wicks, and sand or wick drains. The most ambitious program called for the installation of numerous well points, both in and around the mound, to remove groundwater thus relieving the internal pore pressure. Such a solution would incur long-term operating expenses, involve disturbance of the mound and adjacent cultural deposits for electrical and mechanical system installation, would not strengthen the areas of slope failure, and would probably have to be used in conjunction with some method of mechanical restraint.

The excavation of deep interceptor trenches into the zone of the failure plane which would be filled with crushed stone and contain drain pipes would accomplish two purposes. The crushed stone would strengthen the slope while the drains would remove excess water. It is also possible that simple stone-filled trenches without drains would serve the same purpose. As in many other methods, the impact on the archaeological deposits and mound matrix would be very high.

Other dewatering methods that were more sympathetic to the archaeological integrity of the site included the installation of vertical or horizontal sand or wick drains. Sand drains are simply 15-cm-wide, sand-filled bore holes that pass through the slope failure plane and serve to carry off excess water. A fairly new methodology avoids the necessity of drilling through the use of a sheath to insert synthetic wick drains into the soil. The wick drains are only 10-cm-wide and 1.2-cm-thick. Like the sand drains, they serve to carry off excess water from the mound interior. Both of these dewatering techniques appear to have the advantage of being low-impact solutions to the problem of excess groundwater. Unfortunately, neither addresses the need to strengthen the areas of present or future slope failures.

In evaluating the possible implementation of any of these proposed solutions, priorities needed to be established to guide our decision-making process. It was clear from the outset that preservation in place through stabilization was our mission. Given this context, more specific priorities can be summarized as follows: (1) The solution cannot negatively impact the archaeological integrity of the mound or associated village area, (2) should minimize visual impacts, (3) must have a sound geotechnical basis and a very high probability of success, (4) should address both the current and future causes of slumping, and, (5) must be economically justifiable.

In addition, it was clear from the geotechnical studies that though the slumping was primarily due to excess pore water pressures acting on the failure surface, our lack of knowledge about the groundwater conditions along that surface could not ensure that drainage alone would be a sufficient remedy. The engineers recommended that some form of mechanical stabilization be used in combination with a drainage technique for greater reliability.

Based on these priorities techniques such as stone piers and columns, retaining walls, matrix replacement, and interceptor trenches were rejected because of the excessive disturbance to the archaeological deposits and the large amount of mound matrix that would need to be removed. The negative visual impact of the addition of large amounts of fill and drastic changes to slope angles ruled out benches, slope flattening, and toe berms. Well point dewatering was considered to be too expensive and of uncertain value due to the low rates of hydrologic conductivity within much of the mound matrix.

The use of a system of wick drains and small diameter soil pin pile patterns appeared to be a potential solution. This combination seemed to answer all of our needs with a minimal impact on the archaeological resources, i.e., no visual impact, sound engineering addressing both the removal of excess water and providing mechanical restraint, and economic feasibility. Further detailed planning of this system was authorized.

Both the wick drains and pin piles are new techniques in the United States with few contractors having the expertise or equipment to perform the work. To be most resistant to deterioration, pin piles consisting of epoxy-coated steel rods or angles are placed in predrilled 15-cm holes and pressure grouted with 3000-4000 psi concrete. Maximum efficiency is gained when piles are clustered in specific locations tied together at the surface with a 1.2- x 0.9-m concrete cap. These clustered pin piles must achieve a density of one per lineal 0.3 m of cap and must reach below the mound fill into the natural subsurface clays and sands, i.e., over 15 m in some cases. At least two continuous walls of pin piles would be necessary to stabilize the current slump areas. The data on hand were not sufficient for the engineers to indicate a more specific pattern for the wick drain installation beyond that of an arbitrary grid layout containing about 1,000 wick drains. Major construction berms would have to be placed on the mound face to enable the equipment to place the pin pile wall system and wick drains. Estimated cost for stabilization of the major west slump was approximately one million dollars and seven hundred thousand dollars for the smaller east slump.

Conclusions

The archaeological research at the Great Knob made it apparent that the mound was essentially completed in the short time span between A.D. 950 and A.D. 1050 and was largely comprised of massive fill units rather than small additive layers. It was also discovered that an internal system of buttressing and drainage planes, as well as external buttresses, had been included as part of the original mound design. The examination of the historical documentation had important results. Despite existing folklore suggesting that past erosion, deforestation, cultivation, and other factors had dramatically altered the mound's shape, our study showed there had been little change since its depiction in the early 1800s.

The engineering study collected information from a number of sources including cores, backhoe trenches, and psiometer and inclinometer tests. This study collected data on groundwater content and distribution, matrix material characterization, mound stability, and prehistoric construction techniques. Unfortunately, the data were not specific enough to determine the precise cause of the slope failures, although it was clear that the ultimate problem was water saturated soil. Based on this general information, a series of engineering solutions were proposed to stop the slumping. These proposed methods were in turn evaluated as to their impact on the Great Knob as an archaeological database and architectural monument.

The issues taken into consideration in determining a course of action included the importance of the mound as a data source on prehistoric culture history and construction techniques, as "monumental architecture," its interpretive and symbolic value in presenting the site to the public, and its visual importance as part of the prehistoric and modern cultural landscape. Our primary dilemma in determining a course of action focused on the fact that all of the engineering options to "save" or "preserve" the mound appeared to have a more negative impact than following a "no action" course. In comparably evaluating these often conflicting values we believe that, for the moment, the preferred approach is to manage passively the slumping until a permanent solution to the problem can be found. In the meantime, the IHPA has continued to monitor the slump zones both visually and instrumentally. In the almost five years since the initial onset of the massive west slump there has been no movement. Given this apparent stabilization it is evident that, in this instance, the passive management decision, when coupled with extensive supporting engineering, archaeological, and historical documentation, has been successful.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Illinois Historic Preservation Agency and Southern Illinois University at Edwardsville. This study was funded by the IHPA and conducted by Mathes Geotechnical Services, Inc. in conjunction with the Contract Archaeology Program, SIUE. Numerous individuals contributed to the success of this project and special recognition is due to Ed Keating, Bob Coomer, Margaret Brown, Darrel Wolff, Jim Collins, and Mike Skele.

Notes

1. M. L. Fowler, The Cahokia Atlas: A Historical Atlas of Cahokia Archaeology, Studies in Illinois Archaeology, no. 6 (Springfield: Illinois Historic Preservation Agency, 1989), 90.
2. C. R. McGimsey and M. D. Wiant, Limited Archaeological Investigations at Monks Mound (11-Ms-38): Some Perspectives on Its Stability, Structure and Age, Studies in Illinois Archaeology, no. 1 (Springfield: Illinois Historic Preservation Agency, 1984).
3. G. M. Mathes, "Report of Geotechnical Studies, Monks Mound Slope Failures" (Report submitted to the Illinois Department of Conservation, Springfield, July 27, 1984).
4. W. J. Graham and D. E. Wolff, "Monks Mound Stabilization, Cahokia Mounds State Historical Site, CDB Project No. 104-021-002" (Report submitted to the Illinois Historic Preservation Agency, Springfield, March 28, 1988).
5. M. Skele, The Great Knob: Interpretations of Monks Mound, Studies in Illinois Archaeology, no. 4 (Springfield: Illinois Historic Preservation Agency, 1988).
6. J. M. Collins, M. L. Chalfant, and G. R. Holley, "Archaeological Testing of the Slump Area on the West Face of Monks Mound, Madison County, Illinois" (Report submitted to John Mathes and Associates, Inc., Columbia, Illinois, April 15, 1986).
7. E. Benchley, "Mississippian Secondary Mound Loci: A Comparative Functional Analysis in a Time-Space Perspective" (Ph.D. diss., University of Wisconsin-Milwaukee, 1974), 62-64, 66-67.
8. C. J. Bareis, "Report of 1972 University of Illinois-Urbana Excavations at the Cahokia Site," in Cahokia Archaeology: Field Reports, Illinois State Museum Research Series, Papers in Anthropology, no. 3 (Springfield: Illinois State Museum, 1975), 13-14.
9. E. Benchley, "Summary Field Report of Excavations on the Southwest Corner of the First Terrace of Monks Mound: 1968, 1969, 1971," in Cahokia Archaeology: Field Reports, Illinois State Museum Research Series, Papers in Anthropology, no. 3 (Springfield: Illinois State Museum, 1975), 16-20.
10. Collins, Chalfant, and Holley, "Archaeological Testing."
11. Fowler, The Cahokia Atlas, 95.
12. Benchley, "Summary Field Report," 19.
13. N. A. Reed, J. W. Bennett, and J. W. Porter, "Solid Core Drilling of Monks Mound: Technique and Findings," American Antiquity 33, no. 2 (1968): 137-148
14. C. J. Bareis, "Report of 1971 University of Illinois-Urbana Excavations at the Cahokia Site," in Cahokia Archaeology: Field Reports, Illinois State Museum Research Series, Papers in Anthropology, no. 3 (Springfield: Illinois State Museum, 1975), 9-10.
15. Bareis, "Report of 1972," 12-14.
16. Benchley, "Summary Field Report."
17. K. Williams, "Preliminary Summation of Excavations at the East Lobes of Monks Mound," in Cahokia Archaeology: Field Reports, Illinois State Museum Research Series, Papers in Anthropology, no. 3 (Springfield: Illinois State Museum, 1975), 21-24.
18. McGimsey and Wiant, Limited Archaeological Investigations.
19. Mathes, "Report of Geotechnical Studies."
20. Collins, Chalfant, and Holley, "Archaeological Testing."
21. Graham and Wolff, "Monks Mound Stabilization."
22. Bareis, "Report of 1971," 8-10.
23. Bareis, "Report of 1972," 12-13.
24. J. M. Collins, G. R. Holley, and W. I. Woods, "New Data on an Old Enigma: The Second Terrace of Monks Mound" (Paper delivered at the 52nd Annual Meeting of the Society for American Archaeology, Toronto, May 7, 1987).
25. Graham and Wolff, "Monks Mound Stabilization," 35-36.
26. Ibid., 36-46.

CHAN CHAN: APORTES PARA LA CONSERVACION DE LA ARQUITECTURA DE TIERRA

Arql.ANA MARIA HOYLE
Independencia 572 - Trujillo
PERU

ABSTRACT

The purpose of this paper is to inform you of our recent experiences in the use of organic aglutinating substances as an alternative to the use of plastic chemicals in the preservation of the earthen architecture at the site of Chan Chan, the capital of the Chimu Empire (9th - 15th C. A.D.). The subjects addressed will be surface consolidation, structural reinforcement, and the protection of the tops of walls.

KEYWORDS

Chan Chan, Conservation, Adobe, Perú.

INTRODUCCION

A partir de 1974, el INC y la UNESCO, han efectuado labores de conservación en Chan Chan. Por falta de recursos técnicos y financieros éstas han sido, en su generalidad, llevadas a cabo a nivel empírico en el mismo monumento, sin tener la posibilidad de realizar un control sistemático y riguroso, ni los análisis físico-químicos in situ. Igualmente, estas limitaciones no han permitido implementar programas integrales de conservación y prevención. No obstante, la experiencia de campo ha aportado conocimientos y soluciones al problema de conservación, con resultados muy positivos que son materia de este documento.

FACTORES DE DEGRADACION

Un complejo conjunto de factores de degradación se presentan interactuando permanentemente en Chan Chan (1). Su proximidad al mar (1000 m. de distancia) favorece una fuerte concentración de sales higroscópicas transportadas por los vientos y depositadas sobre las estructuras (0.54% ClNa-0.09% SO3Na) (2); éstas también se encuentran contenidas en los materiales de las edificaciones (0.84% ClNa/0.74% SO3Na prom.) (3) y en el subsuelo (36.48/67.53 milhimos/cm) (4). Las sales se activan con la humedad relativa ambiental (84%) (5), las precipitaciones pluviales (garúa, lluvias) y la fluctuante napa freática, que, en combinación con los cambios térmicos, causan daños irreversibles en el monumento: Formación de costras, eflorescencia y cristalización de sales y finalmente exfoliación. Además, la humedad ambiental favorece la formación de líquenes, y las precipitaciones pluviales, particularmente las cíclicas de carácter torrencial, producen severos efectos erosivos y causan empozamientos al interior de los recintos. Además, debido a la ausencia de una barrera rompevientos natural la violenta acción erosiva eólica desvasta mayormente cabeceras y paramentos de cara al litoral.

Finalmente, a estos factores se añaden, la mala calidad de albañilería de ciertas estructuras, un suelo de soporte débil con resistencia diferencial en algunos sectores (basado fundamentalmente en rellenos artificiales de basura y desechos de construcción) y las vibraciones imprevistas de los movimientos tectónicos que han causado más de un derrumbe y trituración de muros. (6)

CONSERVACION DEL MONUMENTO

Antecedentes

Los programas de conservación se orientaron a controlar el proceso de deterioro y la acción de los agentes naturales teniendo los siguientes niveles de intervención (7):

a. Refuerzos estructurales.

b. Protección de cabeceras de muros como punto crítico en la preservación de estructuras mediante la aplicación de una capa de mortero estabilizado compuesto de: Arena gruesa y tierra (2:1) y Mowilith DM-1H (Acetato de Polivinilo en Solución) al 5% y 10% en agua. El objetivo fue obtener una capa poco permeable, resistente a la erosión pluvial y al temperismo, complementado con planos inclinados para facilitar el discurrimiento pluvial hacia sectores del muro menos comprometidos con decorados en relieve.

c. Consolidación a nivel de fijación de enlucido-muro y relieve-enlucido, mediante Mowilith DM-1H al 5% en agua; y la fijación de superficies y policromías con Silicato de Etilo 40 disuelto en alcohol etílico de 96% y ácido clorhídrico. Previamente se había experimentado con soluciones acrílicas, Acetatos de Polivinilo, Metracrilato, Nylon Soluble, etc.

d. Instalación de una red de drenaje para la evacuación rápida y eficaz del agua pluvial.

Las lluvias torrenciales del año 83 sometieron a la más dura prueba este tratamiento, el que en su generalidad arrojó una respuesta favorable. La capa de protección de cabeceras impidió la absorción y filtraciones de humedad al interior de las estructuras y anuló la acción de las sales depositadas en ellas. Las superficies tratadas a base de Silicato de Etilo 40 no presentaron erosiones. De otra parte, se evitaron daños por humedad capilar debido a un eficaz funcionamiento de la red de drenaje instalada en el Templo Arco Iris. Sin embargo, los consolidantes químicos de naturaleza plástica presentaron inconvenientes:

a. Su empleo en superficie formó una película impermeable por efecto de una rápida evaporación, que finalmente se exfolió debido a la acción de la humedad y las sales contenidas en la estructura.

b. En las cabeceras de muros se crearon varios problemas. La impermeabilidad de esta capa anuló la capacidad de respiración del muro y evaporación de la humedad contenida, produciéndose activación de sales higroscópicas bajo ésta con deterioro del original. Su rigidez y poca capacidad de absorción, formó, de un lado, una resistencia diferencial con el original; y del otro, un incremento de la velocidad del discurrimiento pluvial, que, acentuado por los declives naturales o artificiales, produjo una severa erosión en el punto de contacto entre ambas superficies y determinados sectores de las estructuras.

Intervención 1987-89

La experiencia prevista nos condujo a reformular algunas acciones de la intervención y a plantear nuevas alternativas, particularmente en relación al tipo de consolidante; partiendo de la consideración que el tratamiento no debe anular las propiedades de permeabilidad de las estructuras, y debe contar con resistencia al intemperismo. De tal manera, era preciso emplear un consolidante con propiedades de cohesión, plasticidad y resistencia a la compresión y que permita mantener la porosidad de los materiales.

Los criterios de intervención, además de los predichos inicialmente, incluyeron:

a. Considerar el carácter irreversible de los consolidantes químicos de naturaleza plástica y su efecto en la estructura molecular del barro.

b. Emplear sustancias consolidantes compatibles con la naturaleza del barro y las condiciones básicas de un adecuado tratamiento de conservación.

c. Orientar la intervención hacia un tratamiento mecánico de protección y prevención contra agentes naturales.

1. Materiales

Como sustancia consolidante, optamos por emplear mucílago de tuna (Opuntia ficus indica) usado tradicionalmente en las construcciones de tierra y en la restauración de Chan Chan en los años 60. Previamente apreciamos que esta sustancia ha tenido una buena respuesta como aditivo en morteros para recomposiciones de frisos en Tschudi, y no ha producido problemas de alteración del material.

Los mucílagos son ésteres de ácido sulfúrico (polisacárido complejo), contenidas en las células vesiculares de los tejidos parenquimáticos de la Tuna. Son insolubles al agua, pero tienen capacidad de absorverla y retenerla; en contacto con ésta forman soluciones viscosas. Complementariamente las pectinas que se relacionan íntimamente con ellas y las gomas, forman sustancias coloidales que se convierten en jaleas. (8)

Esta sustancia mucilaginosa, tiene propiedades de conglomeración, además inhibe y selecciona gérmenes, por lo que su uso favorecería la consolidación de materiales y se evitaría la formación y proliferación de bacterias y líquenes.

La extracción de mucílago se efectúa de la siguiente manera: 350 gr. del interior de la hoja cortada, remojada en 0.5 lts. de agua natural durante 24 hrs. Esta sustancia se mezcla con agua natural al 5%-10% a fin de rebajar su densidad y lograr su aplicación y buena penetración en el muro (3 cm. promedio). Su tiempo de utilidad se extiende a sólo 48 hrs. a partir de su remojo inicial; pasado este tiempo, sus células entran en estado de descomposición y pierde el 85% de su viscosidad.

Esta sustancia, en solución al 5%, ha sido empleada como consolidante y como aditivo para morteros, en las proporciones siguientes:

Cuadro 1

TIPO DE MORTERO	PROPORCIONES MATERIAL (*)					
	Arcilla gr.	Tierra gr.	Arena Fina gr.	Arena Gruesa gr.	Confitillo (Piedra 5 ml.) gr.	Mucílago 5% lt.
- Resanes enlucidos a	-	333	666	-	-	0.25
- Resanes enlucidos b	333	-	999	-	-	0.25
- Resanes enlucidos c	-	333	-	666	-	0.25
- Asentado de Adobes	-	333	-	666	-	-
- Estuco	-	333	-	666	333	0.25
- Capa Protec. Cabeceras	-	333	-	666	333	0.25

(*) Proporciones estimadas con un margen de error al 10%

2. Tratamiento:

Los niveles y procedimientos de la intervención continuaron siendo los mismos, con modificaciones parciales que se indican en cada rubro.

a. Refuerzos Estructurales:

Tuvieron los siguientes lineamientos: Consolidar y estabilizar la estructura colapsada o en proceso; anular la exposición del interior de la estructura a los fenómenos del intemperismo; y, crear barreras rompeviento y clausura de accesos no originales como medida de prevención ante la fuerza erosiva eólica y el tránsito indiscriminado del turismo.

El procedimiento consistió en la limpieza de los escombros y la eliminación de los materiales salinos y sueltos. Se efectuaron calzaduras de las bases, además de recomposición de los vacíos y reforzamiento de cabeceras. Los paramentos fueron elevados hasta alcanzar el nivel de éstas, dejándolos aptos para el tratamiento de protección. Se utilizaron adobes de forma y composición semejante a los originales, y la técnica de albañilería siguió el patrón arqueológico empleando mortero según las proporciones dadas en el Cuadro 1. Las superficies de las partes agregadas fueron cubiertas con un estuco que incluye confitillo y mucílago (Cuadro 1), con lo que se obtuvo una superficie bastante plástica y rugosa que se integra, sin confundirse con el original.

La intervención también consideró la reposición de secciones de paramentos desplomados, mediante el uso de puntales que iban devolviéndolas paulatinamente a su posición original. Se utilizaron llaves de amarre de algarrobo y adobe (según el caso), además de mortero, con el propósito de fijarlos a la estructura sólida.

Como medida de prevención contra la acción eólica, se levantaron algunos muros orientados de Este a Oeste, hasta la altura de la evidencia arqueológica; de tal manera se devolvió la barrera rompeviento original que protegía un importante sector decorado del palacio Tschudi.

b. Protección de Cabeceras de Muro :

Intervención destinada a controlar filtraciones, excesivo humedecimiento, erosión pluvial, penetración de sales higroscópicas y la abrasión eólica en las cabeceras originales. Además de los criterios referidos anteriormente al uso de consolidantes, la intervención se orientó a anular los fuertes planos inclinados, adecuando las cabeceras de manera tal, que permitan una distribución homogénea del agua de lluvias, con una absorción y discurrimiento normal en toda la extensión de la estructura, eliminando con ello, su concentración y fuerza erosiva.

El procedimiento consistió en la preparación de la superficie original luego de la eliminación de materiales sueltos, costras, y el material del tratamiento anterior. Se extranjeron las sales con papetas de papel absorbente humedecido con agua destilada y alcohol al 5%, y se consolidaron las superficies con mucílago al 5%. Posteriormente se aplicó la capa de protección, consistente en uno o dos tendidos de adobes modernos, y sobre ésta, el mortero de barro con mucílago al 5% (Cuadro 1). Una vez deshidratada, se cubrió la superficie con un aguaje de arcilla bastante líquida, con el objeto de eliminar la porosidad gruesa producida por la presencia del confitillo; así como para uniformizar el color de la superficie del conjunto trabajado. Esta capa, de naturaleza reversible, es la que resistirá los embates de la naturaleza, previniéndose, así, la degradación del original.

En los casos de muros decorados con rombos, solamente se colocó una capa de adobes, siguiendo el diseño de la decoración, y únicamente en donde se presentaron buenas condiciones de estabilidad y resistencia estructural. Esta capa, actuando literalmente como una cubierta, reemplaza al mortero de protección, siendo también, totalmente reversible.

c. Consolidación de Enlucidos y Relieves:

Considera la adherencia de estucos y relieves desprendidos o en proceso al muro soporte; y, el resane de grietas y vacíos.

Efectuamos inicialmente la limpieza general de las superficies, retirando el material grueso de escombros, las chorreras y adherencias finas acumuladas por deslizamientos de barro. Las sales se eliminaron con la misma técnica descrita para las cabeceras. Los desprendimientos fueron adheridos al muro mediante inyección de mucílago en solución al 5%-10%; y también insertando mortero con mucílago bastante licuoso.

De otra parte, las grietas y vacios fueron resanados con mortero (Cuadro 1) aplicado en dos capas y humedeciendo previamente el área con mucílago. La primera con arena gruesa, dejando una textura irregular a fin de facultar la adherencia de la segunda; y luego ésta, con materiales finos, a la que se le dió un acabado de textura regular luego de la deshidratación.

d. **Protección de Estructuras:**

La medida adoptada para evitar la degradación por factores medio-ambientales y también de orden turístico, fue la protección de los paramentos de banquetas y las rampas con un muro moderno a distancia de 0.20 mts. respecto al original, y una capa de adobes, respectivamente. De otra parte, los pisos arquitectónicos fueron protegidos con su propio material de escombro, cuyas superficies se adecuaron con planos inclinados hacia puntos centrales alejados de las estructuras a fin de que el agua evacúe hacia espacios abiertos y no se acumule contra los muros. Esta intervención es complementaria a la red de drenaje.

COMENTARIO

Llegar a conclusiones sobre la respuesta del tratamiento general y el comportamiento del mucílago a los tres años de la intervención, es bastante prematuro. Sin embargo, informaremos sobre los resultados de corto plazo bajo condiciones climatológicas normales.

Los refuerzos estructurales han solucionado problemas de estabilidad de muros, y se ha logrado una efectiva protección de la estructura interna expuesta por derrumbes y otros. De otra parte, la protección de paramentos con muros modernos, ha garantizado la prevención de daños por intemperie y permitido satisfacer exigencias de orden turístico, por cuanto se mantiene la configuración arquitectónica del sector intervenido.

El tratamiento de las cabeceras ha sido optimizado, aunque no se presenta como una solución concluyente. La ventaja de esta técnica en su conjunto, es que mantiene la permeabilidad del muro, debido a que el mucílago no altera la porosidad de los materiales. De esta manera, la inevitable migración y cristalización de sales contenidas que se produce en el nivel superior de las cabeceras afectará solo los materiales modernos que pueden ser fácilmente reemplazados.

La anulación de los planos inclinados ha permitido evitar la concentración y evacuación peligrosa del agua y las fuertes erosiones en determinados puntos de la estructura, habiéndose dado mas bien, una absorción homogénea en toda la superficie de las cabeceras debido a su capacidad de permeabilidad; facultad que, agregada a la ausencia de rigidez, ha evitado las erosiones a nivel del contacto entre la capa de protección y la superficie original, así como también un discurrimiento acelerado y total del agua pluvial que conllevaría acumulaciones en las bases de muros y una consecuente acción capilar.

El inconveniente que presenta este mortero en el tratamiento de estructuras,es su relativa resistencia a la erosión pluvial. Las mezclas que incorporaron mucílago como mordiente respondieron mejor a las lluvias estacionales normales; sólo se presentaron leves erosiones con un mínimo de pérdida de material fino. Por lo tanto debemos preveer su poca resistencia frente a lluvias de carácter torrencial que deberá ser salvada con elementos eventuales de protección (techumbres portátiles, plásticos, etc.).

En cuanto al tratamiento de superficies, la adherencia de enlucidos y relieves al soporte ha dado resultados positivos . Los resanes de grietas y vacíos han complementado la adherencia de superficies y subsanado posibles filtraciones al interior de los muros. En lo que respecta a la consolidación de las superficies, solamente se efectuó un ensayo en el Palacio Tschudi consistente en la aplicación de mucílago al 5% con brocha directa. Inicialmente se produjo un cambio de color, sin embargo en un corto tiempo fue retornando paulatinamente a su tono original.

En general, el tratamiento de estructuras y superficies con mortero mucilaginoso, ha demostrado buena resistencia a la abrasión eólica. Queda por experimentar lo correspondiente a sus cualidades patológicas en la generación de bacterias y líquenes.

Como corolario final indicamos que el mucílago es compatible con el adobe de Chan Chan. Como sustancia consolidante no forma películas impermeables, cohesiona y da resistencia a los materiales. Además permite reiterar la aplicación de la sustancia en la misma zona tratada, así como el empleo de otro consolidante. Estas cualidades son favorables debido a que el mucílago pierde sus propiedades de cohesión luego de un tiempo (no conocido), obligando a repetir el tratamiento.

En vías a mejorar el tratamiento en relación a la resistencia del consolidante, se han venido desarrollando pruebas de laboratorio con mucílago al 5,10,20,30, 40 y 50% en agua, mediante diversas técnicas de aplicación, sobre adobes salinos y sin contaminación. En principio se observa una buena receptividad de la sustancia en ambos. A medida que se aumenta el porcentaje del mucílago, se incrementan la densidad de la solución y la resistencia de la superficie. Pero, la absorción es más lenta (alcanzando siempre 3 cm. promedio) y se produce una alteración inicial del color. Estas muestras toleraron también la penetración de solución de Silicato de Etilo 40, y se comprobó, una vez más, la inalteración de la porosidad, debido a que fue posible la extracción de sales contenidas mediante papetas. En la búsqueda de soluciones, ambos consolidantes bien pueden utilizarse en niveles de tratamiento complementario. Estas pruebas aún están en observación.

En lo que a medidas de prevención se refiere, seguimos considerando de prioridad la instalación de un sistema de drenaje por el potencial pluvial cíclico que ocurre con una frecuencia de 7 a 25 años, no obstante, aún subsiste el problema de su implementación por los restos arquitectónicos y culturales subyacentes. Solo ha sido posible la instalación de pozos colectores en el sector de tumbas del palacio Tschudi, debido a la inexistencia de vestigios culturales bajo éstas.

De otra parte, la instalación de una barrera rompevientos vegetal propuesta en la zona de la playa para contrarrestar la acción eólica, no traería efectos favorables al monumento. La velocidad y fuerza eólica contraída por la mecánica de su desviación ocasionaría mayores daños. Solo sería efectivo si se implementa una serie de barreras a través de la zona urbana arqueológica, lo cual obviamente es imposible. En este sentido, hemos optado por recomponer las grandes murallas perimetrales, e interiores de los palacios (orientadas E-W) a manera de rompevientos, que han aminorado significativamente la fuerza y acción erosiva eólica.

CONCLUSIONES

1. El tratamiento a base de Mucílago de Tuna Brava, se asume como una alternativa al uso de consolidantes de naturaleza plástica, por sus propiedades de aglutinamiento, porosidad y plasticidad.

2. Se debe precisar un mantenimiento minucioso y permanente del monumento como una de las medidas preventivas de mayor importancia para su conservación.

3. Implementar un programa integral de conservación y prevención permanente, que debe considerar la instalación de laboratorios para análisis físico-químicos in situ, que promueva el conocimiento de la problemática de Chan Chan y garantice soluciones mas eficaces para su conservación.

Reconocimiento: Participaron en el trabajo expuesto el equipo técnico del INC-LL: Rest. Héctor Suárez, Rest. Carlos del Mar, Rest. Carlos Castañeda, Arql. Arturo Paredes y Arql. Antonio Murga; contando con la asesoría del Químico Prof. Carlos Cano del INC-Cusco, y las recomendaciones del Rest. Ricardo Morales G., a quienes extendemos nuestro agradecimiento.

NOTAS

1. R. Morales, "La Conservación de estructuras y decoraciones de adobe en Chan Chan", El Adobe. Simposio Internacional y Curso-Taller sobre Conservación del Adobe, (Lima-Cusco-Perú: UNESCO, 1983): 109-111.

2. N. Rosario Chirinos, "Análisis de muestras procedentes de ChanChan-Trujillo" (Informe INC-Perú,1978): 1-2.

3. R. Morales, "La Conservación de estructuras y decoraciones de adobe en Chan Chan": 111.

4. U.N.L. "Resultados de los análisis de laboratorio de las muestras de suelo obtenidas en la zona intangible de Chan Chan" (Informe Universidad Agraria de Lambayeque, Perú, 1989) 1-2.

5. ONERN, "Inventario, evaluación y uso racional de los recursos naturales de la costa" Cuenca del Río Moche, Vol. I (Lima-Perú, 1973): 44-50.

6. A.M. Hoyle, A. Paredes, "Proyecto Chan Chan: Investigación, Conservación, Restauración y Puesta en Valor" (Informe preliminar, INC-LL/FAT-BCR, 1987-1988).

7. R. Morales, "La Conservación de estructuras y decoraciones de adobe en Chan Chan" : 111-112.

8. E. Claus y V. Tylera. "Gomas y mucílagos" (Tesis de Grado U.N.T. 1965).

ABSTRACT

Ancient Panjikent (AD 5-8th cent.), situated some 55 km east of Samarkand, has been under excavation from some forty years. An excavated area of some 6 hectares, has yielded a town with hundreds of two-storied houses, a ruler's palace, two temples, streets, and bazaars encircled by city walls. The mud-brick and adobe (pakhsa) buildings of Panjikent which originally reached a height of some 10-12m (preserved up to about 7m), were decorated with murals and sculptures that have now gained worldwide recognition. There exist enormous problems of conservation and exhibition at Panjikent. These involve the creation of an open-air museum, like that at Pompei, where visitors may be introduced to the town as a whole. This fascinating work and the resolution of these problems would greatly benefit from international cooperation.

KEYWORDS

Sogdian civilization, Silk Route, dead city,open-air museum.

PANJIKENT; A PRE-ISLAMIC TOWN IN CENTRAL ASIA

Dr.Boris Marshak
The State Hermitage Museum
191065 Leningrad
USSR

Panjikent is one of the most important Central Asian archaeological sites. The city of Panjikent is in Tadjikistan (the Tadjik Soviet Socialist Republic) and is situated some forty miles east of Samarkand. Panjikent exists today and is located on the Zerafshan river. Ruins of early medieval Panjikent were discovered on the hills south of the modern town. (Belenizki, 1980;Azarpay,1981;Belenizki,Marshak,1971).

Since 1946 about a half of the city datable to the eighth century A.D. has been excavated by Soviet archaeologists. Panjikent was founded in the fifth century. Some buildings (part of defensive city walls and two large temples with their spacious yards) were constructed towards the mid-fifth century A.D. There are also some houses of the sixth to seventh century A.D. The walled town (excluding the citadel) encompassing an area of 13.5 hectares was very crowded with narrow streets framed with rows of shops and even vaulted alleys. Houses of wealthy people were two to three stories and had many rooms and principal halls, resembling miniature palaces. Now the height of their ruins reaches 6 to 7 meters.

One third of houses were once adorned with superbly executed paintings and no less skillful wood carving. About 722 A.D. some houses were burned by the Arab conquerers and wooden beams, panels, statues became carbonized.

Panjikent demonstrates the highest point of development of the pre-Islamic culture of Sogdiana. Sogdian merchants controlled trade and commerce along the "Silk Route", the main artery of communication between the West and the East. The excavations of Panjikent have a world importance because it is now the most studied town along the ancient silk roads.

Walls of all buildings and vaults of some ground floor rooms were constructed with mud bricks and pisé (or using a local term pakhsa). After excavation of these walls it is very difficult to preserve them. Panjikent was declared to be open-air museum more then ten years ago. Thousands of tourists from many countries are visiting the site. However, we are at very beginning of the work of establishing a real museum.

Fig.1. Façade of the 7th house dismanteled from additional mud-brick masonry (early 8th century).

Fig.2. Vaulted alley with the walls from pisé divided into large blocks.

Fig.3. Ground floor room with its vault.Early 8th century.

I am an archaeologist and not a technical specialist and so in my paper I want only to show our problems for challenging the specialists who. I hope, can solve them. There are some destructive natural agents like rain and snow, ground water with salts and instability of half-ruined constructions. Now we must remove all sculptures and murals painted upon clay plaster. The Hermitage restorers have their own methods of conservation and removing of Panjikent murals, clay sculptures and burned wood carvings. They use PBMA for reinforcing the murals before removing and paraffin to strengthen charcoal (Kostrov,1954).

Another problem is an esthetic one. It seems necessary to be very careful with introducting modern roofs of concrete, plastic, glass and metal for protection of ruins because these materials inevitably destroy the effect of a dead city resembling Pompei.

There are three ways to present the structures to the public:

1.As ruins protected from further destruction without elements of the reconstruction.
2.As partly reconstructed buildings (with artificially reinforced construction and wall materials) which would be open for visitors.
3.As roofed buildings with museum exhibits inside open to guided tours.

There are also so awkward objects as the unpaved streets and the city walls (their height is about 7 meters in present condition).

The experience of more than forty years of excavations has shown us that the walls were practically invulnerable if protected from the effects of moisture. The walls of the main hall of Temple I built in the fifth century were in good condition until 722 A.D. The hall had only three walls and was opened to the columned portico facing the outside. The unfired clay reliefs dating from the 6th century A.D. in the portico of Temple II also were in good condition until the early 8th century. Now for protecting a wall we use only some rows of additional mud brick masonry above its remnants and the additional clay plastering of its lower part.

For walls which are to be excavated later we must use several methods of protection including new masonry above ruins, chemical reinforcement of old bricks and plasters, insertion of special framework into constructions and special drainage systems. During restoration of the buildings which had been excavated decades ago it would be possible to reconsruct the damaged surface using documentary drawings and photographs. In

Fig.4. Lobby with two doors and two windows for the stair-case. Early 8th century.

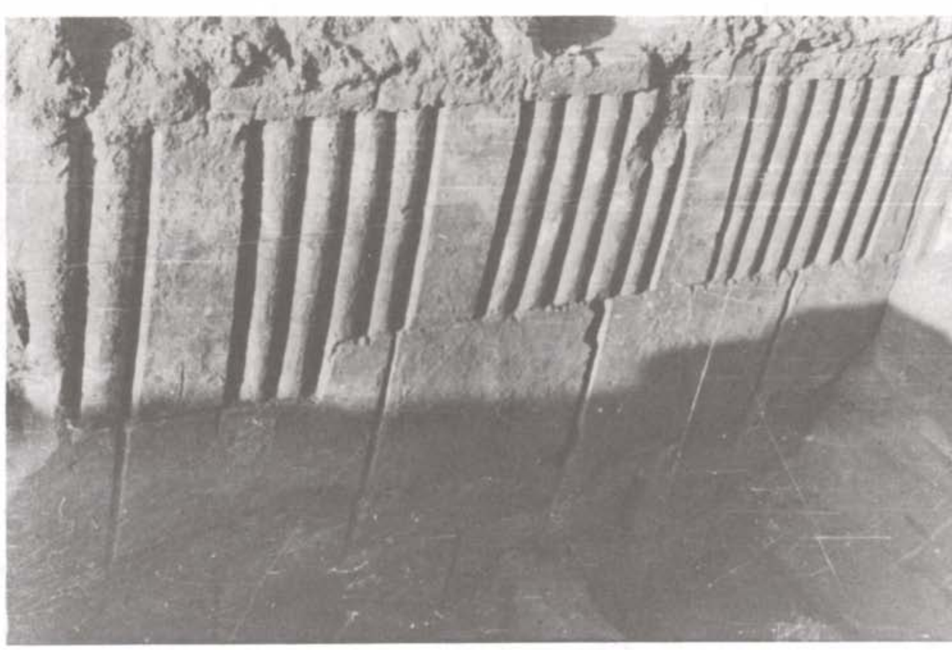


Fig.5. Room with pisé walls. Half-columns were carved in pisé blocks. Early 8th century.

Fig.6. Two-storied house. Below a vaulted ground floor room. Early 8th century.

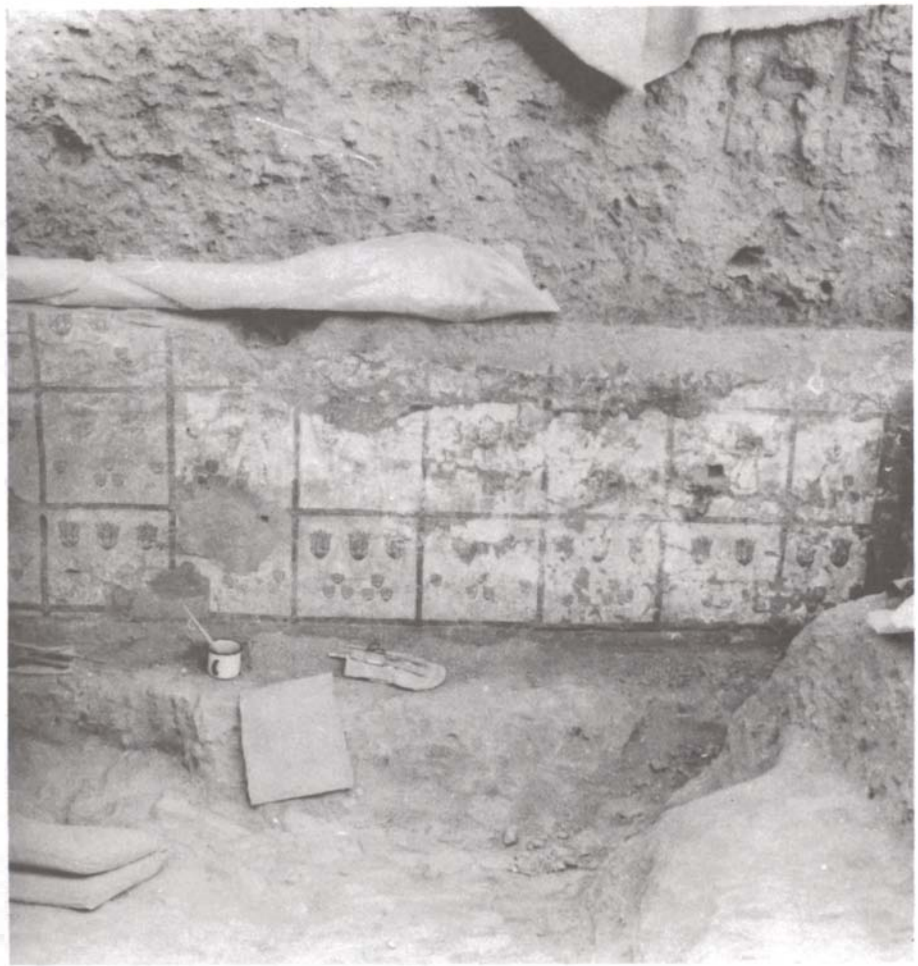


Fig. 7. Ornamental mural.6th century.

Fig.8. Lion-throne of the Goddess Nana. Clay statue. 7th century.

this case it would be also useful to make new bricks and plaster from clay with some kind of modern special long-lasting mediums. It could be dangerous to keep murals and sculptures <u>in situ</u> which may be replaced with modern replicas because now we have no way to make originals strong enough in the climatic conditions of Central Asia. In Panjikent there are dry hot summers and cold snowy winters. It would be useful to search for the best way of preparing exact and long-lasting copies from modern materials.

Our problems are too sophisticated to be solved without collaboration with our foreign colleagues. The great importance of the site itself and the possibility of testing many scientific approaches and technical means must be stressed. I think it would be beneficial to establish an international conservation program for Ancient Panjikent, the main artistic center of the Silk Route civilizations.

REFERENCES

Azarpay, Guitty with contributions by A.M.Belenitskii, B.I.Marshak and Mark J.Dresden 1981 — Sogdian Painting. Berkeley. Los Angeles. London.

Belenizki, A.M. 1980 — Mittelasien. Kunst der Sogden. Leipzig.

Belenitski, A,M., B.Marshak 1971 — "L'art de Piandjikent." Arts Asiatiques XXIII. Paris.

Kostrov, P.I. 1954 — "Tekhnika zhivopisi i konservatsiia rospisei drevnego Piandzhikenta." Zhivopis' drevnego Piandzhikenta. Moscow.

RESTAURATION DES MURAILLES DE SANA'A, YEMEN DU NORD
AMELIORATION DU ZABOUR', METHODE TRADITIONNELLE DE CONSTRUCTION EN TERRE

Myriam Olivier, Ali Mesbah et Willy Adam,
Laboratoire Géomatériaux
ENTPE, Ecole Nationale des Travaux Publics de l'Etat
69 518 Vaulx-en-Velin Cedex, France

ABSTRACT

In Northen Yemen, one of the traditional types of construction, based on on-site fashioned earth, called zabour, is going to disappear because of economic reasons, more particularly the high cost of manpower.,

Special studies have been carried out about the wall of Sanaa, the capital of Yemen, in order to have this type of construction renewed. The studies aimed at modernizing this process though keeping its specificity (the elaboration is handmade in a very unsophisticated way). The tedious part of the work, consisting of kneading the earth, has been removed thanks to the use of a mixer. The quality and the durability of the product are guaranted by the use of a hydraulic stabilizer and to the measure of the quantity of water used for kneading. The laboratory studies carried out in Yemen proved that it was possible to reach a dry or wet resistance of about 3MPa.

This new technology is the result of an on-site experiment, which has enabled us to define recommendations for the manufacture of zabour on-site.

KEYWORDS

Zabour, Yemen, Laboratory and on-site experiments, Dry and humid resistance, Modernisation of a technologie,

Les murailles de Sana'a, avant le début des travaux

Introduction

Le gouvernement de la République Arabe du Yémen a lancé depuis plusieurs années des opérations de restauration de la vieille ville de Sana'a. Après mise au point des projets et les marchés, les travaux sont suivis par le "Bureau Exécutif pour la Sauvegarde de la Vieille Ville de Sana'a", organisme dépendant directement du Cabinet du Premier Ministre du Yémen. Il est aussi important de noter que la ville de Sana'a a été classée *"Patrimoine de l'Humanité"*, en 1980, par l'UNESCO. Les chantiers de restauration de bâtiments publics, de mosquées et de maisons sont très nombreux. De même, des opérations sont en cours relatives à l'assainissement, aux pavages des rues et au ramassage des ordures ménagères.

La reconstruction d'une partie des murailles de Sana'a fait partie des projets du Bureau Exécutif. Le début de leurs destructions est postérieur à 1962. Ensuite le développement de l'urbanisme, associé au non-entretien du reste des murailles, ont entraîné soit leur destruction totale, soit leur disparition partielle entre les bâtiments. Il faut aussi déplorer l'utilisation du Wadi[2] comme voie de circulation, ce qui a causé en 1982, la destruction d'un magnifique pont construit en continuité avec la muraille. Seule une partie de la muraille reste visible et à peu près accessible. C'est celle qui fait l'objet du projet de restauration. Elle va du Wadi jusqu'à 100 m environ de la porte de Bab El Yémen, et mesure environ 400 m.

L'une des techniques utilisées pour la construction de la muraille, le zabour, est actuellement sur le point de disparaître, supplantée par la construction en parpaings de ciment. Les connaissances empiriques accumulées depuis des siècles sont entre les mains de maîtres-maçons (les Ustas), âgés, pour la plupart, de plus de 70 ans. Cependant, pour conserver à la muraille son aspect originel, il a été décidé d'utiliser cette technique, mais en essayant de retrouver scientifiquement les bases de cette technique. La participation française s'est donc située sur un plan purement scientifique et technique et n'a donc pas eu pour objet de remettre en cause les options déjà choisies concernant la politique de restauration et de reconstruction. Celle-ci a été de plusieurs ordres : transformation du projet architectural d'origine en dossier technique, étude expérimentale en laboratoire de la fabrication et de la stabilisation du *Zabour*, transposition des résultats d'études sur le site (méthodologie de suivi du chantier de fabrication et mise en oeuvre du *Zabour*, introduction de l'utilisation d'un malaxeur) et introduction de notions de suivi de chantier (comparaison des quantités prévues à l'estimatif et réalisées, contrôle de qualité,...). Ce sont essentiellement les quatre demiers points qui seront présentés dans cet article.

Contexte de la restauration

Décider de restaurer ce mur a soulevé l'alternative suivante : reconstruire en place une muraille similaire à celle qui existait 200 ou 300 ans auparavant, ou essayer de conserver, dans leur état actuel, les vestiges de l'ancienne muraille. La première solution a été retenue par le Bureau Exécutif et a été appliquée pour l'élaboration du projet.

Les études ont débuté en 1986, grâce à la participation de la République Démocratique de Corée (Corée du Nord) qui a, d'une part, effectué un lever topographique très précis du mur actuel et des constructions avoisinantes et d'autre part, réalisé un premier projet de restauration de ce mur, ne prenant en compte que l'aspect extérieur de la structure. En juin 1988, l'ENTPE a été sollicitée par les Ministères Français des Affaires Etrangères et de l'Equipement, afin de fournir au Bureau Exécutif pour la Sauvegarde de la Vieille Ville de Sana'a un appui technique pour la réalisation des pièces techniques du Dossier de Consultation des Entreprises et pour le suivi des travaux. Celui-ci a consisté en la mise à disposition, auprès du Bureau Exécutif et de l'entreprise retenue, d'un ingénieur du Laboratoire, Willy ADAM, de mars à décembre 89, pour résoudre les problèmes de chantier et pour réaliser les études nécessaires à la mise en oeuvre concrète du *Zabour*, et en deux missions de suivi effectuées, en juin et décembre 1989, par Myriam OLIVIER.

Le projet

1. L'état actuel : La muraille de Sana'a est construite suivant un profil très spécifique au Yémen du Nord. Mais son aspect originel est difficile à imaginer à partir de son état actuel. Cependant, il est possible de trouver, au Yémen des structures identiques, en bien meilleur état. C'est le cas du mur d'enceinte de Saada, ville du nord, en limite du désert.

Le corps de la muraille est constitué de deux murs de *zabour*, montés sur une maçonnerie très résistante, et enserrant un remblai argilo-sablonneux. Un "garde corps"extérieur est réalisé en *zabour* sur une hauteur qui devait être d'environ 1,5 à 2 m. La largeur utile du dessus du mur varie de 3 à 5 m.

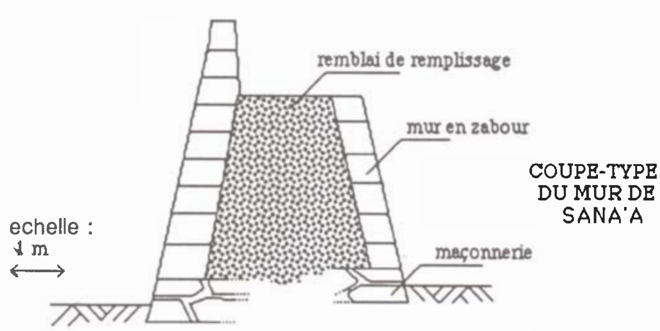
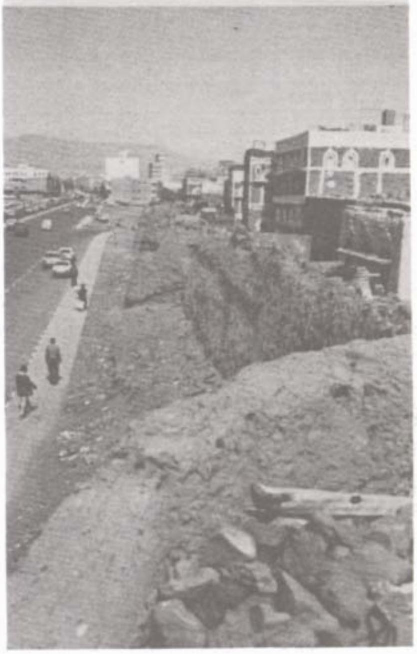


figure 1 : coupe type originelle du mur de Sana'a

Le *zabour* est la principale technique traditionnelle de construction en terre du Yémen du Nord. Le sud du pays utilise également la technique de l'adobe et surtout la construction en pierre. Il consiste à fabriquer des boules de terre argileuse, très humides, puis à les mettre en place à l'avancement, sur le mur, extérieur du mur



de façon à réaliser des “boudins” carrés de section 60x60cm environ. Ceux-ci sont relevés aux angles des murs, de façon à créer un chaînage vertical, donnant ainsi un aspect rayé aux constructions locales qui atteignent couramment des hauteurs de 20m.

2. Présentation du projet : Comme on le verra plus loin, cette technique artisanale est lente à réaliser et très consommatrice de main d'oeuvre. Or, le niveau de vie local s'étant fortement élevé lors des dix dernières années, cette technique a tendance à disparaître au profit du béton et du parpaing de ciment, jugés plus modernes, plus économiques et plus fiables.

Dans le cadre du projet de restauration de la muraille de la Vieille Ville de Sana'a, le laboratoire Géomatériaux de l'Ecole Nationale des Travaux Publics de l'Etat a réalisé une étude sur la technique traditionnelle du zabour en vue de mettre au point les spécifications techniques relatives à sa préparation et à sa mise en oeuvre sur chantier. Le but visé n'était pas d'introduire une technique nouvelle dans ce pays mais, à partir de celle qui existe déjà, de proposer des améliorations pour arriver à un produit fini fiable, homogène, résistant, ayant une bonne tenue à l'eau et pouvant être préparé et mis en place par les artisans locaux sans difficultés majeures.

Outre les aspects laboratoire et réalisation expérimentale sur le site, nous avons travaillé à la mise au point du projet initial, pour y introduire les contraintes de site et tenir compte des matériaux employés. C'est pourquoi, tout en essayant de respecter l'aspect originel du mur, le projet actuel présente quelques modifications avec la muraille ancienne. Ainsi :

- en raison de l'urbanisation qui s'est développée à l'intérieur du mur depuis 1962, la largeur originelle du mur a dû être modifiée. Les écrits anciens signalent que "quatre cavaliers pouvaient galoper de front sur le mur", ce qui correspondrait à une largeur de 5 à 6 m, et est corroborée par l'emprise du mur que l'on distingue encore au nord de la ville. En revanche, sur la partie sud, objet des travaux, l'épaisseur résiduelle du mur varie, sur la majeure partie du tracé, à la base de 2 à 5 m et en haut de 2 m à 30 cm (!). Aussi, afin de ne pas trop empiéter sur les propriétés bâties, la largeur finale en tête de mur ne dépassera que rarement 1,5 m. De plus, pour éviter de détruire certaines maisons directement fondées sur le mur, celui-ci sera par endroits, déplacé de 0,5 à 1 m vers l'extérieur,

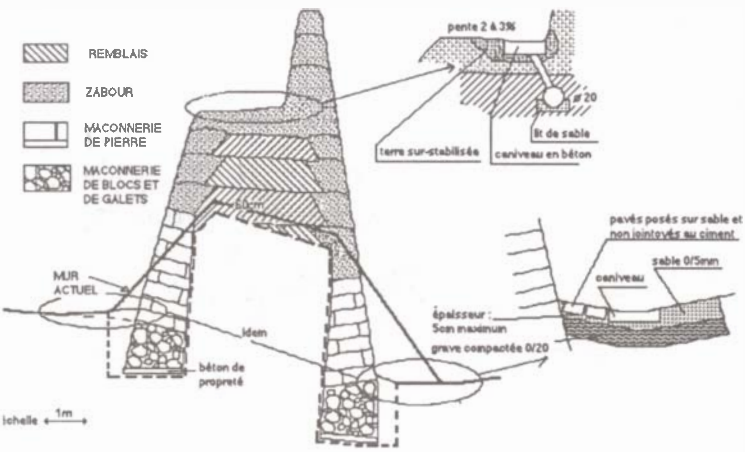


figure 2 : coupe type du projet de restauration du mur de Sana'a

les cours, à l'intérieur du mur

- un soubassement en pierres équarries a été prévu à la base du mur comme cela existait sur l'ancien mur. Ces pierres sont en basalte, matériau qui a déjà été utilisé pour restaurer le mur il y a environ 150 ans comme on le voit sur une partie encore visible du Mur Sud. Il faut cependant noter que le mur d'origine avait probablement une fondation en pierres sédimentaires blanches comme on le voit sur le bord du Wadi. Ce type de pierre est plus facile à tailler, mais est en revanche plus érodable.

- dans tous les cas, la technique de construction de la maçonnerie est identique à celle utilisée pour le mur d'origine, à savoir : pierres bien équarries à l'extérieur et maçonnerie plus rustique à l'intérieur. Cependant celle-ci a été faite avec un mortier de ciment, au lieu d'un mortier de terre (technique ancienne) afin de garantir une meilleure tenue dans le temps de la structure restaurée.

Fabrication traditionnelle du zabour

La préparation et la mise en place du Zabour s'accompagnent d'un rituel assez impressionnant quand on y assiste pour la première fois. Si le malaxage de la terre peut être assimilé à une danse bien rythmée où pieds et mains s'altement pour mélanger intimement la terre, la pose du Zabour par contre est une valse où les boules de terre montent et descendent à une cadence régulière. L'harmonie des gestes, le rythme, les chants d'accompagnement montrent que les artisans se plaisent à faire ce travail et exécutent un numéro de leur folklore.

Mis à part l'aspect cérémonial, la préparation de la terre est une opération longue et fastidieuse. La terre disposée en grand tas est tout d'abord arrosée d'eau et abandonnée ainsi pendant 3 à 4 jours. Ce temps est nécessaire pour permettre à l'eau de s'infiltrer, de cheminer à travers les pores du sol et d'imbiber toute la terre du tas. Après cette période d'humidification commence la phase proprement dite de malaxage. Le tas de terre est pétri, étalé avec les pieds, remis à nouveau sous forme de tas en ramassant des mottes de la périphérie et en les lançant vers le milieu du tas. Ce cycle d'étalement - rassemblement de la terre se renouvelle jusqu'à ce que le matériau atteint le niveau de plasticité, de cohésion désiré. Vient ensuite la formation des boules de terre ; chaque artisan récupère une petite motte de terre, la pétrit plusieurs fois sur une surface lisse et dure et la met pour terminer en boule. On se retrouve ainsi, en fin de préparation avec un tas de boules de terre qui ressemble à des petits pains attendant la cuisson.

Place maintenant à la valse des boules de terre. L'USTA (maître-maçon) se positionne dans la zone de travail, attrape une à une les boules de terre qui lui sont lancées par les ouvriers, les oriente et les projette dans la partie de l'ouvrage à réaliser. Tout se déroule rapidement à une cadence rythmée sur le chant d'accompagnement. Au fur et à mesure que s'accumulent les boules de terre, la bande de Zabour se dessine et prend forme. Quand un morceau de la bande est prêt, l'USTA arrête momentanément le jeu des boules, comble en tassant avec la main les creux qui se sont formés et achève la finition des parois extérieures, en la polissant avec la main.

malaxage de la terre et fabrication des boules de zabour

Modernisation de la technique

Cette présentation sommaire de la technique de fabrication du Zabour au Yémen montre clairement qu'elle s'accompagne d'un délai considérable entre le début de la préparation de la terre et sa mise en place effective. Pour le chantier de la muraille de Sana'a où environ 2000 m^3 de Zabour doivent être réalisés, cette technique traditionnelle, si on devait la maintenir telle quelle, entraînerait un allongement excessif de la durée du projet, un coût de production du m^3 de Zabour exorbitant et un alourdissement de la gestion du chantier. Aussi a-t-il fallu l'adapter pour la rendre plus opérationnelle.

1. Le malaxage : La première innovation apportée réside dans la mécanisation de la préparation de la terre. Au malaxage manuel, on a substitué un malaxage mécanique[3]. Les résultats enregistrés sont très intéressants du point de vue économique et technique :

- Réduction importante de la main-d'oeuvre et gain de temps. Avec 3 personnes (1 technicien et 2 ouvriers), il a été possible de préparer des gâchées de 0,01 m^3 en 6 à 8 minutes. Chaque gâchée comprend un malaxage à sec des constituants solides (terre-sable-ciment) pendant 2 minutes puis un malaxage humide avec l'ajout d'eau. Cette dernière est toujours versée sous forme de pluie. La méthode manuelle traditionnelle demande 45 minutes pour malaxer le même volume, après avoir pré-humidifié la terre pendant plusieurs jours. Une fois les quantités fixées et après que les ouvriers se soient fait la main, la préparation de la terre devient pure routine, reproductible en série. Ils retrouvent alors l'appréciation visuelle d'un maçon expérimenté.

- Meilleur contrôle du dosage en eau et meilleure qualité du malaxage. Alors que pour une préparation traditionnelle la teneur en eau varie d'un endroit à un autre du mélange (au laboratoire, pour de faibles quantités de terre malaxée manuellement, on a observé des variations de 5 points de teneur en eau), le malaxage mécanique permet une répartition uniforme de l'eau dans le mélange. Les petites variations enregistrées (de l'ordre de 0,5 à 1 point de teneur en eau) viennent des phénomènes d'évaporation dus au temps écoulé entre la fin du malaxage et la mise en place de la terre et surtout, du pétrissage de la terre pour la confection des boules. Elles ont peu d'influence sur la résistance finale. (voir figures 7 & 8).

2. La stabilisation au ciment : L'autre innovation vient du fait qu'un liant, du ciment en l'occurrence, a été ajouté à la terre pour la stabiliser. Au Yémen, jusqu'à présent, aucune tentative en ce sens n'a été faite. Pour protéger la terre brute contre les intempéries, les artisans préfèrent épaissir les ouvrages, ce qui entraîne souvent un surdimensionnement des éléments structuraux. Avec la stabilisation au ciment, il a été possible d'obtenir un matériau aux bonnes caractéristiques mécaniques et parfaitement résistant aux intempéries (voir § VI).

De plus, la méthode traditionnelle de préparation de la terre n'est plus appropriée, car il est effectivement impossible de faire "macérer" la terre stabilisée plusieurs jours à cause du phénomène de prise assez rapide en présence d'un stabilisant. D'où l'intérêt supplémentaire de l'introduction du malaxage mécanique. Les études ont été réalisées avec 0, 4, 6, 8 et 10% de ciment, qui sont des valeurs courantes pour la fabrication de mortiers de terre. Pour les travaux, c'est finalement une stabilisation à 6% de ciment qui a été retenue.

mise en place du zabour par l'Usta

3. La mise en oeuvre du zabour : Le dernier point concerne la réalisation même du mur. Pour assurer le transfert des études de laboratoire sur le chantier de construction et s'assurer de la bonne coordination entre les techniciens du Bureau Exécutif et l'Usta (maître-maçon), un essai de mise en oeuvre sur le site a été réalisé les 11, 13 et 14 décembre 1989. Le travail expérimental sur site s'est fait progressivement. Au début de l'expérimentation, l'ensemble des opérations de dosage, de malaxage et de mise en oeuvre étaient suivis par W.ADAM et M.OLIVIER. Puis, petit à petit, elles ont été déléguées à l'ingénieur du chantier et au technicien du Bureau Exécutif. Lors du troisième essai expérimental, l'ensemble des opérations a été réalisé par les Yéménites, avec un parfait consensus entre les différents intervenants (entreprise, Bureau Exécutif et Usta).

Cette phase a ainsi permis un excellent transfert de données expérimentales et de technologie sur un site réel et a donné aux différents intervenants l'occasion de retrouver la maîtrise d'une technique traditionnelle grâce à une approche scientifique des problèmes. L'expérience acquise lors de cette expérimentation demande cependant a être confirmée par une mise en oeuvre rapide sur le mur lui-même. Malheureusement, le report de cette phase à 4 ou 5 mois fait perdre une grande partie des acquis de l'entreprise et de l'Usta.

Etudes faites en laboratoire

1. Principe des études : La détermination des paramètres de chantier a été faite à partir d'essais de laboratoire réalisés au Yémen, en liaison avec le laboratoire du Ministère des Travaux Publics et celui de la Faculté d'Ingénieur de l'Université de Sana'a. Après avoir examiné la préparation traditionnelle du Zabour et identifié les paramètres de base (granulométrie et composition des matériaux, liants, teneur en eau, mode de malaxage, mode de mise en place, cure) qui s'y rattachent, des séries d'éprouvettes ont été préparées en faisant varier ces paramètres. Elles ont ensuite été soumises aux essais suivants : compression simple, tenue à l'eau lors d'essais de remontées capillaires et essai d'immersion complète.

A partir des résultats obtenus, il est possible d'évaluer l'influence, sur les caractéristiques mécaniques (résistances à sec et humide) du Zabour, du mode de préparation de la terre (malaxage manuel, malaxage mécanique), de la teneur en eau de fabrication, de l'ajout de ciment et des conditions de cure.

2. Choix des matériaux : Au Yémen, il n'existe pas un matériau type pour la préparation du Zabour. Les artisans se contentent de prélever la terre qui se trouve immédiatement à leur portée. Ainsi, suivant le savoir-faire de l'Usta et suivant le type de sol disponible, la qualité du Zabour varie d'une région à une autre : on peut facilement passer d'un Zabour compact, résistant et dur comme un rocher à un Zabour fissuré, friable au simple toucher et lessivé par les intempéries.

L'un des points importants du travail a consisté à choisir, pour la restauration de la muraille, une terre permettant d'optimiser les caractéristiques mécaniques et le comportement du Zabour . A cet effet, 8 carrières situées aux alentours de Sana'a ont été visitées et leurs échantillons soumis à des essais d'identification. Nos investigations se sont limitées, pour des raisons économiques, à la région de Sana'a. Les résultats obtenus ont été analysés et comparés à ceux obtenus sur deux échantillons de Zabour retenus pour leur qualité. L'un provenait de la région de Saada et l'autre directement de la partie de la muraille en bon état de conservation. Parmi ces carrières, deux ont retenu particulièrement notre attention. Des difficultés pour acquérir des terrains de la première carrière nous ont conduit à choisir finalement la seconde (carrières de Beit Mulkat et celle de Beit Al Saal'a).

Le matériau provenant de Beit Al Saal'a est un 0/50 mm. Les résultats des essais d'identification font apparaître pour ce sol, un déficit assez important en sable. Pour y remédier, on a mélangé cette terre


vue du mur expérimental en zabour (janvier 1990)

avec un sable propre provenant de la région de Saada, dans la proportion de quatre volumes de terre de Beit Al Saal'a pour un volume de sable. Les gros éléments du sol ont été également écartés afin d'éviter la formation de billes pendant le malaxage (tendance de la terre à s'agglomérer autour des cailloux) et l'apparition de zones d'hétérogénéité dans le Zabour. Les matériaux d'origine et remanié ont donné les résultats suivants :

- courbes granulométriques et sédimentométriques (voir figure 3).
- essai normalisé au bleu de méthylène (uniquement sur le matériau remanié) :
sur le (0 / 0,1 mm) VB = 2,38, soit sur le sol total, (0 / 16 mm) VB = 1,22
- limites d'Atterberg : matériau brut WL = 31,8 Wp = 20,3 IP = 11,5
matériau remanié WL = 30,6 Wp = 22,7 IP = 8

D'après la classification RTR[4], la fraction 0 / 16 mm se situe, pour le matériau brut en A2, et pour le matériau remanié en A1. D'après la classification LCPC[5], le matériau brut est une argile peu plastique, et le matériau remanié un sable argileux.

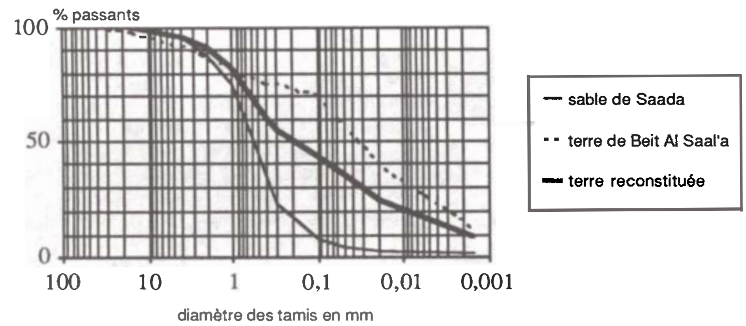


figure 3 : courbe granulométrique des matériaux utilisés


Vues des travaux de maçonnerie en cours

3. Déroulement des essais

3.1 Confection des éprouvettes : Les éprouvettes ont été confectionnées avec de la terre malaxée suivant les deux techniques mais l'accent a été surtout mis sur le malaxage mécanique. Dans les deux cas, une fois achevé le malaxage, on a fabriqué les éprouvettes en utilisant un moule en métal (ø=9,5 cm et h=12 cm). La terre déposée à l'intérieur du moule n'a été ni compactée ni compressée. Dans le cas des préparations "assez sèches" (teneur en eau comprise entre 23 et 26 %), une petite tige métallique a été utilisée pour tasser légèrement la terre et pour éviter la formation de trous à l'intérieur de l'éprouvette. Au-delà de 27 %, la terre malaxée s'apparentait davantage à une boue et il n'a pas été nécessaire de la tasser. Le démoulage des éprouvettes se faisait immédiatement après leur fabrication. Pour éviter des phénomènes de collage ou adhérence dans la zone de contact terre-moule, on a pris soin d'intercaler entre la terre et la paroi intérieure du moule huilée au préalable, un plastique assez rigide. Les éprouvettes ont été pesées et mesurées pour calculer leurs densités sèches à partir de la relation : γ_d=Ph /(S x (1+w),

où : - Ph est le poids humide de l'éprouvette en gr - S, sa section en cm^2
- h, sa hauteur en cm - w, la teneur en eau du matériau

Les éprouvettes en terre non stabilisées ont été conservées à l'air libre et celles stabilisées au ciment, sous une bâche en plastique polyane bien fermée. L'influence du type et de la durée de la cure sera évaluée par la variation des résistances en compression simple.

3.2 Essai de résistance à sec : Des essais de résistance en compression simple à sec, après conservation des éprouvettes, ont été réalisés à 5, 10, 15 et 30 jours afin d'étudier l'influence de l'âge sur la résistance du Zabour. Seules les éprouvettes fabriquées à partir du Zabour traditionnel ont été écrasées à plus de 30 jours. Afin d'obtenir des essais homogènes, avant l'essai proprement dit, on a interposé un système antifrettage entre l'éprouvette et les plateaux de la presse.

3.3 Résistance humide : Cet essai est réalisé sur un matériau généralement âgé de 15 jours qui a été pendant au moins 24 heures soumis à un essai de remontées capillaires. Pour les éprouvettes stabilisées, une partie a été soumise à l'essai de remontées capillaires immédiatement après la cure sous la bâche, tandis qu'une autre a été mise à sécher à l'air libre 1 ou 2 jours avant l'essai. Pour deux séries d'éprouvettes, la conservation sous bâche a duré uniquement 5 jours ; ensuite, elles ont été mises à sécher à l'air libre pendant 10 jours avant l'essai de capillarité.

3.4 Essai de remontées capillaires : Les éprouvettes ont été posées sur un lit de sable, puis soumises à une pression capillaire très faible entretenue par la circulation d'eau dans un tissu épais, déposé sur le sable et dont les bords baignaient dans deux récipients contenant de l'eau.

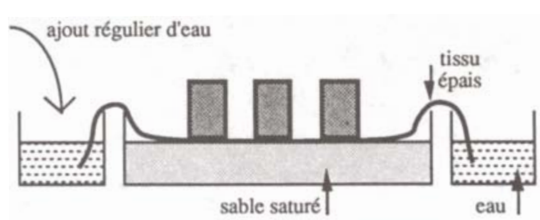


figure 4 : essai de remontées capillaires

Les récipients étaient disposés de manière à ce que le niveau de l'eau et la surface supérieure du lit de sable soient dans un même plan horizontal. Un contrôle suivi tout au cours du déroulement de l'expérience a permis de maintenir constant le niveau de l'eau dans les récipients. Le poids des éprouvettes a été relevé régulièrement pour calculer la quantité d'eau absorbée par le matériau.

4 Influence de la teneur en eau de fabrication

4.1 Variation de la densité sèche : D'une manière générale, il n'existe pas une relation bien nette entre densité sèche et teneur en eau. Les courbes obtenues pour les teneurs en eau étudiées (23 %<w< 34 %) montrent que la densité sèche a tendance à diminuer avec l'augmentation de la teneur en eau. Ceci s'explique : pour ces teneurs en eau, le matériau non stabilisé est proche de la saturation et les densités sèches obtenues se calent sous la courbe de saturation : $\gamma_d=\gamma_s/(1+w.\gamma_s/\gamma_w)$, notée en trait plein sur les figures 5 et 6. Les points correspondants aux teneurs en eau très élevées se situent au dessus de cette courbe, ce qui est dû aux écoulements d'eau libre observés lors du démoulage des éprouvettes.

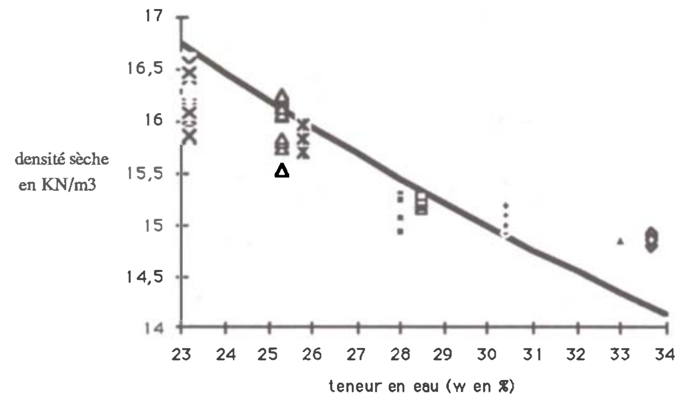


figure 5 : (densité sèche / teneur en eau) pour le matériau non stabilisé

On observe également une grande variation des valeurs de densité sèche à teneur en eau constante (par exemple, pour le matériau stabilisé à 6 % de ciment, γ_d varie de 1,40 à 1,59 pour w=24,8%). Ces résultats peuvent s'expliquer par le fait que la quantité de terre introduite dans le moule lors de la fabrication d'une éprouvette varie d'une éprouvette à une autre, surtout à teneur en eau faible, et comme aucune force n'a été utilisée pour compresser la terre, la répartition des vides, le tassement et la cohésion finale de l'éprouvette s'en trouvent modifiés.

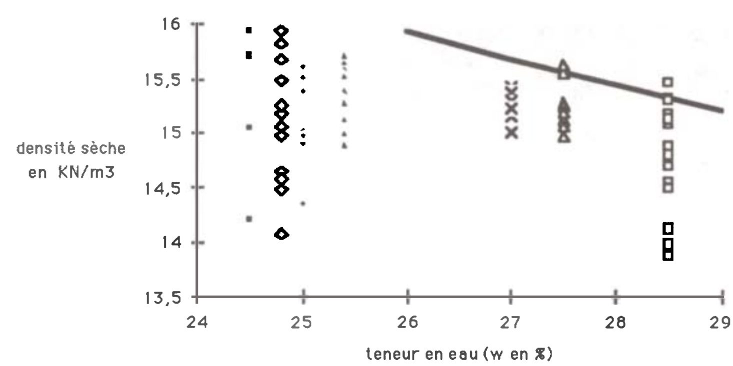


figure 6 : (densité sèche / teneur en eau) pour le matériau stabilisé à 6% de ciment

En comparant les valeurs de densité sèche pour le matériau brut et le matériau stabilisé, on constate qu'on obtient de plus fortes valeurs de densité sèche pour le matériau brut que lorsqu'il est stabilisé. L'ajout du ciment entraîne une baisse de densité, car la chaux libre présente dans le ciment entraîne une floculation quasi instantanée des argiles, qui s'oppose à la mise en place du matériau. On se trouve alors avec un pourcentage de vides plus élevé avec les matériaux stabilisés .

4.2 Résistance en compression à sec : Pour le *matériau non stabilisé*, les valeurs les plus élevées en résistance sont enregistrées pour les teneurs en eau "faibles" (w<26 %). Pour ces valeurs, le matériau est légèrement compacté et non moulé, mais sa mise en place est difficile et la dispersion des résultats est grande. Quand la teneur en eau croît, on retrouve la même tendance que pour la densité sèche, à savoir la résistance tend à diminuer.

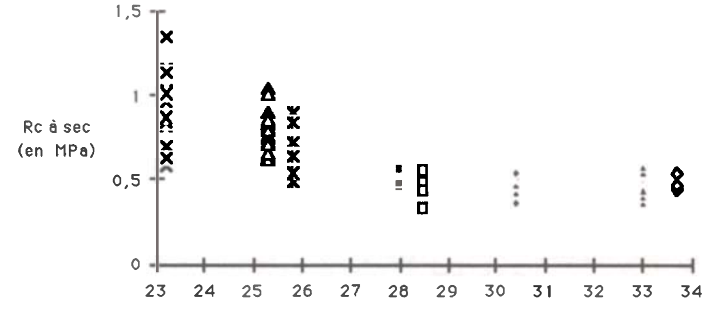


figure 7 : (Résistance à sec / teneur en eau) pour le matériau non stabilisé

L'*ajout du ciment* en faible proportion entraîne un gain de résistance considérable. Pour le matériau brut, la résistance se situe autour d'une valeur moyenne de 0,8 MPa, alors qu'après stabilisation à 6% de ciment, elle est aux alentours de 3 MPa ; soit 3,5 fois plus élevée.

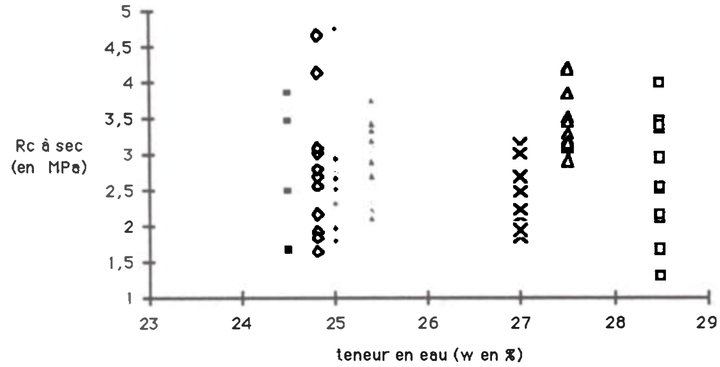


figure 8 : (Résistance à sec / teneur en eau) pour le matériau stabilisé à 6% de ciment

4.3 Résistance en compression après essai de remontées capillaires : L'influence bénéfique du ciment apparaît très nettement pour les résistances humides. Alors qu'après l'essai de remontées capillaires, le matériau brut présente des résistances quasi nulles (Rc humide ≈ 0,03 MPa), le matériau stabilisé à 6% de ciment garde une tenue excellente (Rc humide ≈ 3 MPa). De plus, on observe dans ces conditions, un retrait, donc une micro-fissuration, très faible. Pour 4% de ciment, la résistance humide diminue (Rc humide ≈ 2 MPa) et le matériau devient plus érodable, ce qui nous a amené à choisir, pour le chantier, une stabilisation à 6% de ciment.

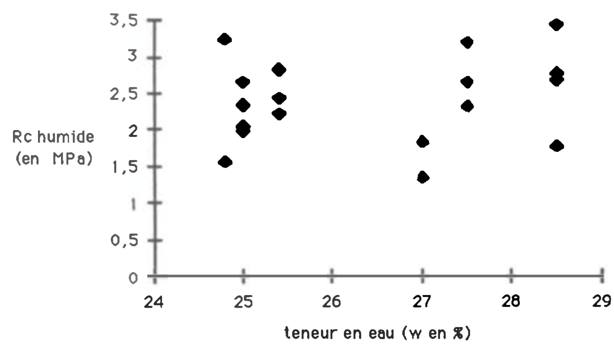


figure 9 : (Résistance Humide / teneur en eau) pour le matériau stabilisé à 6% de ciment

4.4 Conclusion sur les conditions de suivi de chantier : Il ressort de cette analyse que la teneur en eau à elle seule, ne suffit pas pour caractériser le Zabour et prévoir son comportement. Les recommandations écrites ont donc été établies pour assurer une bonne qualité du matériau et de la structure neuve. Elles ont pour principaux objectifs de garantir l'homogénéité de la fabrication et une résistance minimale du zabour. Elles concernent la durée et le mode de malaxage, l'ajout d'un stabilisant, la teneur en eau et surtout le mode de mise en place du zabour. Tous ces paramètres visent à obtenir la meilleure adéquation entre résistance et densité sèche. Sur la figure 10, les ❐ correspondent aux résistances sèches, les Δ aux résistances humides pour la teneur en eau retenue (27<w< 27,5%), alors que les ■ et ▲ correspondent aux autres teneurs en eau.

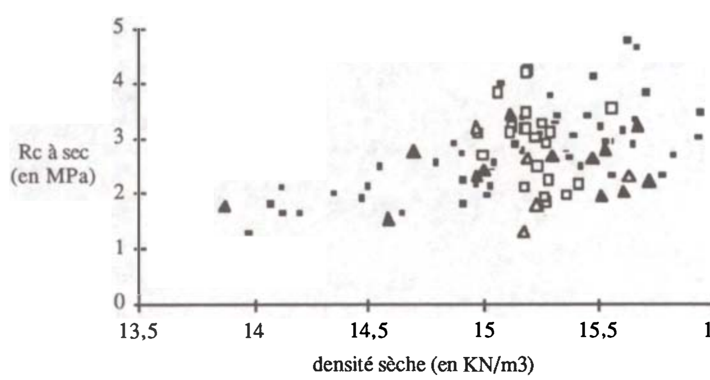


figure 10 : courbe (Résistance / densité sèche) pour le matériau stabilisé à 6% de ciment

Expérimentation sur site

1. Réalisation de l'expérimentation : Le transfert des résultats de laboratoire au chantier lui-même s'est fait au cours d'une expérimentation grandeur nature, en collaboration avec l'entreprise et les Ustas yéménites. Cette phase très importante et très intéressante a permis :

- d'effectuer les réglages du malaxeur pour obtenir une bonne homogénéité du matériau,
- établir une méthode simple de calcul et de dosage sur chantier des quantités de sable, de terre et d'eau, méthode qui pourra être mise en oeuvre par l'ingénieur de l'entreprise yéménite
- optimiser les temps de fabrication et de mise en oeuvre du *Zabour* pour limiter les phénomènes de prise anticipée du *Zabour* stabilisé au ciment,
- établir une relation de confiance avec l'Usta chargé de la mise en oeuvre du *Zabour* - celui-ci avait en effet l'habitude d'utiliser un matériau plus humide et non stabilisé - et l'amener à modifier légèrement son mode de travail afin de limiter ensuite les risques de fissuration par retrait.

D'autre part, lors de cet essai, deux types de ciment Portland, l'un gris, l'autre blanc ont été utilisés afin d'évaluer l'influence de la couleur du ciment sur l'aspect extérieur (variation de couleur surtout) du *Zabour*. Après 2 ou 3 mois de séchage à l'air libre, la couleur finale étant stabilisée, le Bureau Exécutif pourra effectuer son choix quant au type de ciment à utiliser pour stabiliser le *Zabour* du mur.

2. Recommandations pour l'exécution du Zabour : Cette expérimentation en site réel a permis de montrer les étapes où se situent les différences de fabrication et mise en oeuvre entre le *Zabour* traditionnel et "moderne", et ainsi de faire apparaître les points délicats et le suivi à effectuer.

2.1 Qualité du Zabour : le paramètre principal est la teneur en eau du mélange terre-sable-ciment. La teneur en eau optimale est de 27 %, pour le corps du mur. Pour effectuer le lissage de l'extérieur du mur, il est nécessaire d'augmenter très légèrement (+0,5%) cette teneur en eau.

2.2 Temps de fabrication : la mise en place d'un second malaxeur s'est avérée indispensable car, lorsque la teneur en eau est optimale, il faut de 6 à 8 mn pour fabriquer une gâchée de Zabour, alors que la fabrication et la mise en place des boules de *Zabour*, avec l'équivalent de ce matériau, par les aides de l'USTA, ne prend de 4 à 5 mn.

2.3 Mise en place du Zabour : afin de limiter la fissuration dans le mur, due au séchage de la terre et au retrait lors de la prise du ciment, il est nécessaire de s'assurer que le minimum de vides subsiste après mise en place des boules. Pour cela, les points suivants sont à surveiller :
- les boules doivent être placées directement à la jonction de la tranche de *Zabour* en cours de fabrication et la tranche précédente, il est, en effet, insuffisant de simplement repousser ce *Zabour* pour le mettre en place ainsi qu'on procède traditionnellement,
- des rainures devront être réalisées dans l'ancien mur afin de faciliter l'adhérence du nouveau *Zabour* sur celui-ci. De même que précédemment, les boules de *Zabour* devront être lancées directement dans le creux entre l'ancien et le nouveau mur,
- à la fin d'une phase de travail, il faudra également terminer le *Zabour* par une forme en escalier afin de favoriser ensuite l'adhérence avec le nouveau *Zabour*.
- une cure de 15 jours du zabour sera réalisée en disposant une bâche sur le mur.

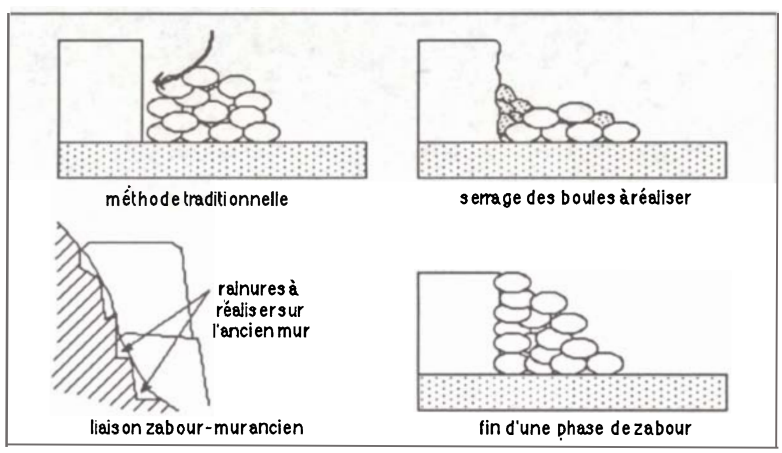


figure 11 : Mise en place du Zabour

Etat d'avancement des travaux

Les travaux d'exécution du mur ont débuté en août 89 par le nettoyage des abords extérieurs du mur. Ce n'est que courant septembre 89 qu'ont démarré les travaux de fondation et de maçonnerie. Fin décembre 89, ces travaux étaient achevés sur près du tiers de la longueur totale du projet (400m).

En avril 1990, les maçonneries de la base du mur sont réalisées sur 90% à l'extérieur du mur, mais les travaux à l'intérieur du mur restent difficiles à entreprendre car ils se déroulent en domaine privé. Le mur expérimental en zabour se comporte très bien,mais le zabour n'a toujours pas été commencé sur le mur lui-même.

Les photos des pages suivantes montrent le site des travaux ainsi que les conditions dans lesquelles ils se déroulent.

Conclusions

Ce chantier montre qu'une technique très traditionnelle peut être modernisée pour s'adapter aux conditions économiques actuelles. De plus, les études de laboratoire ont amené l'appui technique nécessaire pour transformer les connaissances empiriques des Ustas, en connaissances scientifiques quantifiables, vérifiables sur chantier, et qu'il est possible d'introduire dans un Cahier des Charges. Ce point est un point-clé dans la diffusion ou la réhabilitation d'une technique terre, car elle permet de garantir à la fois le maître d'oeuvre et l'entrepreneur en établissant contractuellement les objectifs recherchés et les moyens à mettre en oeuvre pour les atteindre.

Zabour : technique traditionnelle de construction en terre, très spécifique au Yémen Nord. Elle consiste à réaliser des boules de terre argileuse, à l'état plastique, qui seront ensuite projetées sur le mur par le maçon de façon à former un "boudin" carré de 60 cm environ de côté. La construction en place de murs formés d'une succession de ces boudins donne l'allure caractéristique des maisons du Yémen du Nord.(voir §IV)

[2] Wadi : lit asséché d'un fleuve temporaire

[3] malaxeur thermique : SED - CMD 250 LC, modifié ALTECH (05 200 Embrun, France)

[4] RTR : Recommandations pour les Terrassements Routiers

[5] LCPC : Laboratoire Central des Ponts et Chaussées