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PROTECTION AND ENVIRONMENTAL CONTROL OF THE PLASTERED MUDBRICK WALLS AT ÇATALHÖYÜK

Elizabeth Moss

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Supervisor
Frank G. Matero
Associate Professor of Architecture

Reader
Catherine S. Myers
Principal, Myers Conservation

Graduate Group Chair
Frank G. Matero
Associate Professor of Architecture

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ABSTRACT

Çatalhöyük, the preeminent Neolithic site located in south central Turkey, is known for the painted plastered mudbrick walls and relief sculptures discovered by James Mellaart in the 1960s. The current excavation, which includes specialists from various disciplines, is under the direction of Dr. Ian Hodder of Cambridge University. The conservation of the site and architectural elements is being led by the Architectural Conservation Laboratory (ACL) at the University of Pennsylvania under the direction of Frank G. Matero, Catherine S. Myers, and Lindsay Falk. Because the painted plastered mudbrick walls and relief sculptures form an integral part of the architectural as well as the greater socio-cultural contexts of Çatalhöyük, it is imperative that every effort be made to preserve them.

As part of the overall conservation plan for the architectural remains of the site, current research focuses on preventive conservation as a means of controlling damage during and after excavation. It addresses issues reported during excavation of earthen walls and plasters. Research included site investigation, materials analyses, and the creation of simulated models to examine such critical conditions as the effects that moisture, salts, and desiccation have on earthen architecture.

The information presented here should not be interpreted as an isolated work, but rather as part of a holistic conservation program incorporating past as well as continuing study. While past research focused on the consolidation and detachment of the plaster surfaces, this work specifically addresses the mitigation of damage caused immediately upon excavation due to rapid, excessive drying of both the plaster and its earthen substrate. Immediate, non-obtrusive intervention as a form of preventative conservation should be implemented as the first step in a comprehensive conservation program.

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1.0 Project Background

Çatalhöyük is unquestionably one of the most important archaeological sites to be discovered this century. Although hundreds of Neolithic sites have been identified throughout the Near East, Çatalhöyük is unique both for its size as well as the amount and quality of artifacts discovered there.

In November 1958, James Mellaart, the British archaeologist responsible for the excavations at the Neolithic site of Hacilar, discovered two mounds on the Konya Plain in south central Turkey.[1] The eastern mound, covering 32 acres, was identified as Neolithic, and the western mound was dated to the subsequent Early Chalcolithic period. Mellaart immediately gained world attention in 1961 when he began excavating the eastern mound. It quickly became apparent that Çatalhöyük was more than a simple Neolithic village settlement. Evidence from the excavation indicated that Çatalhöyük was in fact a complex urban center of great size and time depth. From 1961 until his excavation closed in 1965, Mellaart uncovered up to 15 organized occupation levels, composed of densely packed buildings built of mudbrick. The earliest occupation period was dated to about 6800 BCE.[2]

Among the numerous artifacts, the excavation produced the unprecedented existence of extensive murals and plaster relief sculpture. The paintings offer a unique view to early human thought through the depiction of animal, human and abstract motifs.

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[1] James Mellart, "Excavations at Çatal Hüyük: First Preliminary Report, 1961," *Anatolian Studies* 12 (1962): 41.
[2] Ibid., "Chatal Huyuk—The World's Oldest City", *Illustrated London News*, Archaeology Section 2245 (May 28, 1966): 26.

To date, these are still the earliest surviving monumental paintings on a man-made architectural background. The only documented earlier examples have been found in natural rock shelters. The paintings in the Paleolithic and Mesolithic rock shelters at Beldibi on the Mediterranean coast near Antalya illustrate good Anatolian examples.[3] Through the discoveries at Çatalhöyük, Mellaart introduced the world to a higher level of sophistication than was formerly known for this period in pre-history.

After four years of excavation, the site was closed in 1965. Fortunately, emergency measures were taken on several of the paintings and relief plasters during excavation. Given the unexpected discovery of the wall paintings and the absence of an integrated conservation program as part of the excavation, the only option for preservation was removal of the paintings and relief plasters from the site. It is through these early efforts that surviving examples exist today in the Museum of Anatolian Civilizations at Ankara.

In 1993, the Turkish government agreed to reopen Çatalhöyük for archaeological and scientific research on the condition that a comprehensive conservation program be included in all stages of the excavation. The current excavation, which includes specialists from various disciplines, is under the direction of Dr. Ian Hodder of Cambridge University. The conservation of the site and architectural elements, including the painted wall plasters and relief sculptures, is being led by the Architectural

[3] Ibid., "The Earliest Frescoes Yet Found on a Man-Made Wall: Remarkable Discoveries in the Excavations at Anatolian Catal Huyuk—Part II," *Illustrated London News*, Archaeology Section 2095 (June 16, 1962): 978.

Conservation Laboratory at the University of Pennsylvania under the direction of Frank G. Matero, Catherine Myers, and Lindsay Falck.

1.1 Architectural Elements at Çatalhöyük

An overview of the architectural elements at Çatalhöyük has been compiled based on published accounts of the site. A total of fifteen successive occupation levels, spanning over a thousand-year period, have thus far been uncovered. The excavation records and documentation of building levels by Mellaart illustrate a continuity of plan from one occupation level to the next. Each level has building types designated for both public and private use. Whereas later occupation levels (I-VI) were destroyed by fire, the earlier levels (VII-X) appear to have been "lived in until they were unfit for human habitation, after which they were pulled down."[4]

1.1.1 Layout/Plan

Çatalhöyük is composed of buildings of rectilinear plan. Archaeological evidence points to the fact that the houses were one story high, accessed through flat roofs. According to Mellaart, "most houses consisted of a living-room, measuring, on the average, some 4 by 5 yards—and one or more subsidiary rooms, which could be arranged

[4] Ibid., "Earliest of Neolithic Cities: Delving Deep into the Neolithic Religion of Anatolian Catal Huyuk. Part II—Shrines of the Vultures and the Veiled Goddess," *Illustrated London News*, Archaeology Section 2170 (Feb. 8, 1964): 194.

in various ways."[5] Hearths are found at the south wall, near the roof entrance. Two "shrines" discovered by Mellart were partially preserved to the roof level. They measured 8'9" (2.7m) and 8'3" (2.5m) high respectively. Mellart used these two rooms as his basis of reconstruction. Based on the height of the plaster relief on the west wall, Mellart determined that the room must have had a clerestory over the center of the building.[6]

1.1.2 Materials

The buildings at Çatalhöyük are more or less regular in plan, and consistent in the use of construction materials. All of the buildings are of mudbrick, without stone foundations, and appear to have been constructed as separate contiguous entities. The bricks appear to have been mold-made with the addition of straw, or a similar organic temper material to control shrinkage and increase tensile strength. The earthen mortar contained visible ash and broken bones.[7] It was presumably obtained from midden sources.

According to Mellaart, "each house bore some architectural ornament in the form of wooden posts, engaged against the wall, plastered over and painted red, plaster

[5] Ibid., "A 7th-6th Millennium Township of Southern Anatolia, Larger than Pre-Pottery Jericho: First Excavation at Catal Huyuk—Part I," *Illustrated London News,* Archaeology Section 2094 (June 9, 1962): 934.
[6] Ibid., "Catal Huyuk in Anatolia: Excavations which Revolutionise the History of the Earliest Civilisations. Part II-Shrines and Buildings," *Illustrated London News,* Archaeology Section 2122 (February 2, 1963): 160.
[7] Ibid., *A Neolithic Town in Anatolia.* (London:Thames and Hudson, 1967), 49-67.

pilasters and ribs and niches."[8] The floors as well as interior walls were plastered. Mellart noted instances where successive replastering of the floors raised their level to over a foot above that of the original floor. A floor in level VI had at least sixty coats of plaster.[9] Mellaart interpreted the site as being composed of both public and private houses, the primary difference being that the public spaces ("shrines") were covered with plaster wall reliefs and paintings. In general, "wooden posts, round or squared, stand against the east and north wall dividing the wall space into 3 sections and 2 overhangs in the wall plaster on the same walls produce a series of panels, which like beams and post are all carefully plastered."[10]

A detailed analysis of the plasters was performed at the Architectural Conservation Laboratory at the University of Pennsylvania in 1996.[11] Chapter Three of this thesis adds to that information with analysis of the physical and chemical properties of the mudbrick.

1.2 Current Conservation Efforts

Because the decorative and symbolic aspects of the plastered walls form an integral part of the architectural as well as the greater socio-cultural contexts of

[8] Ibid., "A 7th-6th Millennium Township of Southern Anatolia, Larger than Pre-Pottery Jericho," *Illustrated London News,* Archaeology Section 2094 (June 9, 1962): 934.
[9] Ibid.
[10] Ibid., "Catal Huyuk in Anatolia: Excavations which Revolutionise the History of the Earliest Civilisations. Part II-Shrines and Buildings," *Illustrated London News,* Archaeology Section 2122 (February 2, 1963): 160.
[11] Evan Kopelson, "Analysis and Consolidation of the Architectural Plasters at Çatalhöyük, Turkey" (master's thesis in Historic Preservation, University of Pennsylvania, December, 1996).

Çatalhöyük, it is imperative that every effort be made to preserve them. A holistic understanding and interpretation of the site relies on the artifacts found within the context of their architectural surroundings. One of the challenging and exciting aspects of the preservation of Çatalhöyük is that there is no single solution. The extent of preservation of the plastered walls may range from written and photographic documentation, to the conservation of whole rooms *in situ*. Preservation may also include the removal of wall sections for treatment off-site, museum storage or display, or replication for visitor interpretation. It is also possible that the solution for the preservation of the site may be the decision to backfill, or rebury selected areas.

Regardless of what forms of preservation are ultimately chosen, the final decision must be based on what is best for each scenario that arises. Although there is room for discussion as to the eventual preservation techniques for specific architectural elements, short-term preventative measures must be taken upon excavation in order to facilitate final preservation decisions.

As part of the overall conservation plan for the architectural remains of the site, this thesis has focused on preventive conservation as a means of controlling damage during and after excavation. It will address issues reported during excavation of earthen walls and plasters. Research included site investigation, materials analyses, and the creation of simulated models to examine such critical conditions as the effects that moisture, salts, and dessication have on earthen architecture.

2.0 Earthen Architecture

Earth is one of the oldest building materials. Mudbrick construction is based on using a modified soil that is molded in its plastic state. It has been the major method of traditional construction throughout the Near East, tracing its origins back to the Neolithic period of initial human settlement. In areas with scarce supplies of stone or wood, the use of mudbrick made from local soils makes economic sense. It is also considered a desirable material in areas with hot summers and cold winters due to its insulating qualities and thermal storage capacity.

2.1 Components

Mudbricks are primarily composed of sand, silt and clay with or without organic binders and tempers. Sand is necessary as a filler to reduce shrinkage. Clay, and arguably silt, are the binders. Analysis has determined that the optimum ratio for making mudbrick is between 60%-80% sand and 20%-40% silt and clay.[12] Sometimes fibrous organic material is added to the mix to improve tensile strength and aid in even drying and weather resistance.[13]

[12] Giacomo Chiari, "Characterization of Adobe as Building Material. Preservation Techniques," in *Adobe: International Symposium and Training Workshop on the Conservation of Adobe.* (Peru:UNESCO, 1983), 35.

[13] Giorgio Torraca, Giacomo Chiari, Giorgio Gullini, "Report on Mud-brick Preservation," *Mesopotamia* 7 (Torino, Giappichelli Editore, 1972): 259-286.

2.1.1 Clay

Clay, the primary binding component of mudbrick, is a hydrophilic phyllosilicate mineral group composed of hydrous layered alumino-silicates. The crystal lattice is formed by bonding extended SiO_4 tetrahedral sheets to octahedral sheets. A sheet is trioctahedral if each oxygen, or OH group is surrounded by three cations. When two cations surround each oxygen or OH group, the structure is dioctahedral. Due to electrostatic forces, the surfaces of the layers predominantly carry negative charges. Thus, they easily attract polar water molecules which cause swelling and contracting of the clay platelets. The layers are held together by weak van der Waals bonds that tie neutral molecules and uncharged units into a cohesive structure via residual surface charges. Van der Waals are the weakest of the chemical bonds, and characteristically define a zone of cleavage.

There are three basic clay groups that may be found in soils used for mudbrick construction: kaolinites, illites, smectites.[14] Kaolinites, composed of only a two-layer structure, are the least reactive clay type in the presence of water. Kaolinite structures are built of one tetrahedral (Si_2O_5) sheet and one octahedral (XO_6) sheet. They have a 1:1 structure in which the ratio of tetrahedral layers equals the octahedral layers. The layers are essentially neutral and are bonded to one another by weak van der Waals bonds.

Illites are a somewhat reactive three-layered clay type with a 2:1 structure. An Al

[14] Hugo Houben and Hubert Guillaud, *Earth Construction: A Comprehensive Guide.* (London: Intermediate Technology Publications, 1994), 27.

octahedral is sandwiched bewteen two SiO_4 tetrahedra. Compositionally, illites are considered alkali-deficient micas.

Smectites, also having a three-layered structure held together by van der Waals bonds, comprise several clay minerals composed of both the dioctahedral and trioctahedral type layers sandwiched between tetrahedral layers.[15] The trioctahedral type includes hectorite and saponite. The dioctahedral type includes montmorillinite, the dominant clay mineral in bentonite, which is produced through the alteration of volcanic ash.[16] Smectites are the most reactive clay type, undergoing extreme swelling and shrinkage in the presence or absence of water. Molecular water containing exchangeable cations can be inserted between each three-layered group of tetrahedral-octahedral-tetrahedral sheets.[17] It is the capacity to absorb water between the sheets that produces expansion. In combination with the weak van der Waals bonds, smectites have excellent cleavage, gliding and expansion capacity.

2.2 Causes of Deterioration

Due to its effect on the clay component of mudbrick, water is the greatest source of deterioration. Moisture in conjunction with wet-dry cycling causes shrinkage cracking, basal erosion, migration and crystallization of soluble salts, and freeze-thaw stressing, all resulting in the mechanical deterioration of mudbrick walls. When in

[15] Cornelis Klein and Cornelius S. Hurlbut, Jr., eds. *Mineralogy*, 21st edition. (New York: John Wiley and Sons, 1993), 513.
[16] Ibid., 513.
[17] Ibid., 501.

contact with water, clay increases in volume, becomes plastic and disperses, leading to loss and structural failure.[18] It has been reported that moisture can decrease the tensile and compressive strength of mudbrick up to 200%.[19] Wall bases, effected by capillary rise from ground and surface moisture tend to collapse due to this phenomenon. Other factors influencing the decay and destruction of earthen architecture include seismic activity, wind erosion, animal activity, and human intervention.

2.3 Earthen Architecture in the Archaeological Context

The exposure of earthen architecture at archaeological sites presents unique preservation concerns. Buried structures and artifacts exist in unique microenvironments created by a wide range of factors including soil type, ground water, buried material, depth and configuration, animal and plant activity, microflora and bacteria. After years of interment, material remains reach an overall equilibrium with the surrounding soil.[20] The destabilization of this environment through the removal of a protective earth covering causes a loss of surface pressure and rapid drying of earthen walls due to surface evaporation, which results in the migration of soluble salts to the surface as well as shrinkage cracking, loss of cohesion, and delamination. Many buried artifacts and structures absorb soluble salts from the groundwater. Through evaporation, soluble salts

[18] Chiari, "Characterization of Adobe as Building Material. Preservation Techniques," 35.
[19] Clifton and Davis, as noted by Alejandro Alva Balderrama and Giacomo Chiari, "Protection and Conservation of Excavated Structures of Mudbrick," in *Conservation on Archaeological Excavations.* (Rome: ICCROM, 1984), 110.
[20] Paul Coremans, "Climate and Microclimate," in *Conservation of Cultural Property*. (Unesco, 1968), 37.

may crystallize on the surface or just below it. The increase in volume of the crystallized salts within porous materials may cause mudbrick and surface finishes to disaggregate and flake, and layers to detach. Much early scientific research was done at mudbrick sites in Iran, where conservators determined that the "period of greatest danger for a newly uncovered work is the first few weeks, for it is then that the remains must face the results of a major unbalancing of the conditions immediately affecting both their internal and superficial parts."[21]

Upon excavation, buried walls experience a transition from slow or inactive to active surface alteration. Exposed walls become a plane of climatic activity. Heat is absorbed and moisture evaporates. Newly exposed walls may be subjected to dramatic temperature changes ranging from the extreme midday heat to cold nights. During periods of extreme heat, the wall surface is warmer than the interior; however, at night, the wall surface may be cooler than the interior. It is possible that slight differences in thermal coefficiencies between the mudbrick walls and finish coats may exacerbate plaster failure. This shift in temperature may result in too much stress for surface finishes.

Wind aids in increasing evaporation, salt formation and rapid dessication. Roots, often present at the interface between walls, floors and fill, or between plaster layers and in cracks, can cause gross macro-failure and detachment, especially upon drying.

[21] Andrea Bruno, G. Bultinck, G. Chiari, C. Trossarelli, "Contributions to the Study of the Preservation of Mud-Brick Structures: Preliminary Report of a Survey of Monuments in Iraq during the Period March-June 1968," in *Mesopotamia* 3-4 (Torino, Giappichelli Editore, 1968-69): 449.

While any exposed surface shall be subject to decay phenomena associated with these mechanisms, the situation becomes more pronounced with the addition of surface finishes such as plasters and paintings. As discreet components applied in one or more layers, these finishes are particularly prone to loss and damage due to inherent layered discontinuity with the support.

It is important to bear in mind when confronted with architectural remains in an archaeological site that they usually exist in compromised conditions due to burial, or even before, as in the case of damage resulting from abandonment. As commonly recognized, structures and artifacts, once buried, undergo initial deterioration. Eventually, they reach a "thermo-hygrometric equilibrium in relation to the surrounding environment."[22] Through the very process of archaeological investigation, the stable environment of burial is disrupted. Once exposed, artifacts and structures change in response to their new environment. Upon excavation, the objects are exposed to changes in relative humidity, moisture content, temperature, air and light. The more gradual the process of excavation, the more likely it is to mitigate damage by slowly acclimatizing the buried remains to the variations of their new environment.

2.3.1 Plastered Mudbrick Walls at Çatalhöyük

As documented through excavations in Iran, Iraq, Syria, and Turkey, the Near

[22] Roberto Nardi, "Conservation of Medieval Structures of Mudbrick and of Fired Brick Laid in Clay," in *5th International Meeting of Experts on the Conservation of Earthen Architecture* (Rome: ICCROM, 1987), 73.

East abounds in mudbrick sites of various ages and degrees of importance. Provided that adequate documentation is performed, few archaeologists or conservators have voiced concern over the practice of destroying architectural remains in order to uncover and study earlier occupation levels. However, due to the cultural and historical significance of Çatalhöyük, every aspect of the excavation is under scrutiny. The importance of the earthen architecture, especially of the architecture, plastered reliefs and wall paintings, cannot be underrated when planning for long-term study, site preservation and interpretation.

The composition and geographic location of the plastered mudbrick walls makes them particularly sensitive to the impact of excavation. Within the first week of excavation, Mellaart noted a painted plastered wall that "was crumbly, and, worse still, honeycombed with animal holes."[23] Root intrusions and later Hellenistic and Roman trenches and pits also jeopardized the stability and integrity of the plastered walls. Impending dust storms and rain hampered the continued excavation, as well as any conservation methods.[24]

By the third season (1963), as the excavation reached lower building levels, Mellaart was faced with structural concerns and safety issues regarding the "heavy mudbrick walls periously lean[ing] at drunken angles and mak[ing] any work in depth in

[23] Mellaart, "The Earliest Frescoes Yet Found on a Man-Made Wall: Remarkable Discoveries in the Excavations at Anatolian Catal Huyuk—Part II," *Illustrated London News*, Archaeology Section 2095 (June 16, 1962): 976.
[24] Ibid.

a restricted space impractical. If wall paintings are found at any great depth, it is not safe to clean them."[25] Partial excavation of the lowest level, X (1), revealed structures in the poorest state of preservation: "Because of its depth and the tremendous weight of five successive shrines (IX-VIA) built on top of it, the walls bulged, the decoration had been somewhat compressed and its west wall was deformed beyond recognition."[26]

During excavation Mellaart and his field supervisor, Ian Todd, noted that painted plastered walls began to deteriorate immediately. The exposed plaster developed large cracks upon drying.[27] Not only did the unprotected walls and plasters themselves suffer, so did the applied design layers. Mellart stated that "upon exposure the flesh-colored bodies turned brown and the pinks either turned grey or faded completely."[28]

Although much of the deterioration experienced at Çatalhöyük occurs immediately upon excavation due to rapid evaporation, in the past much has been due to lack of advance preparation and site protection between seasons. The lack of conservation preparative measures was due to the unexpected discovery of the mural paintings. Writing a decade after the excavation closed, Todd postulated that if a controlled sheltering system "such as an air tent, which was used in Turkey for the first time at Can Hasan III in 1969, had been available, controlled temperature and humidity

[25] Mellaart, "Earliest of Neolithic Cities: The Third Season of Excavations at Anatolian Chatal Huyuk. Part I—Shrines and Images, of 9000 Years Ago," *Illustrated London News* 2169 (February 1, 1964): 158.
[26] Mellaart, "Excavations at Çatal Hüyük, 1963: Third Preliminary Report," *Anatolian Studies* 14 (1964): 73.
[27] Ibid., 39.
[28] Mellaart, "The Teasing of the Great Beasts—From Chatal Huyuk," *Illustrated London News* 2247 (June 11, 1966): 24.

could have been maintained; the paintings would not have dried out.[29] The fragility of the site was particularly apparent in 1965 when the excavation was resumed after having been left unprotected for two years. The published field report from that season reported that "after two successive winters of rain and snow the remains discovered in 1963 had badly weathered, many walls had fallen, others were dangerous."[30]

Immediate dessication , shrinkage, detachment and collapse of the plaster surfaces have also been observed at the site on freshly excavated walls during the past three field seasons. Exposed walls protected by sun and wind-screening shelters display slower dessication than those exposed without protection. One dramatic example of the efficacy of shelter protection was demonstrated in 1997 in a room northeast of Shrine 1. A small area of a freshly exposed wall was subjected to direct sun from an opening in the shelter fabric. Within one hour of exposure, the moist plaster surface deformed and collapsed from rapid dessication, shrinkage and its own weight. Detachment was already aided by the existence of roots at the base plaster-wall interface. Areas immediately adjacent and not exposed to the direct rays of the sun were not affected.[31]

One must remember that unlike living earthen architecture, earthen structures excavated from archaeological sites are rarely preserved *in toto*, with their protective

[29] Ian Todd, *Çatal Hüyük in Perspective*. (Menlo Park: Cummings Publishing Co., 1976), 19.
Also see Appendix B: Weaver, "The Use of an Inflatable 'Air-Dome' to Produce Controlled Conditions for an Archaeological site." *Studies in Conservation,* 18,2 (1973), 88-93.
[30] Mellaart, "Excavations at Çatal Hüyük, 1965: Annual Report," *Anatolian Studies* 16 (1966): 13.
[31] From field observations, August 1997.

roofing or surface finishes. Thus, finished walls, never meant to be exposed to the elements, tend to decay at accelerated rates.

2.4 Conservation Intervention

Historically, most archaeological conservation work has involved the removal of material off site for presentation. Such removal may or may not have been followed with further laboratory treatment. Often, removal of the object from the climatic conditions in which it was found was considered ample conservation. It was not uncommon for wall painting to be cut from supporting walls and displayed devoid of any architectural, historical, or cultural context. Such is the case with the earliest wall paintings discovered at Çatalhöyük. Due to the importance and fragility of the paintings, emergency measures were taken in order to ensure their preservation. Conservation knowledge of the time did not permit the painted plastered earthen walls to be preserved *in situ*, nor was there a plan to interpret the site to the public after excavation. Since one could not guarantee the preservation of the paintings left *in situ*, selected mural paintings and relief sculptures were removed from the walls. Moreover, "it was then decided that the only safe way to conserve this material was to remove all mud plaster from behind the painted surface and replace it with a backing using a reversible synthetic resin,"[32] a technique commonly employed for lime-based mural paintings. Taken in context, this was the only viable solution of the time, and one still practiced in extreme situations today. One also needs to

[32] Pamela Pratt, "Çatal Hüyük Wall Paintings," *Anatolian Studies* 24 (London: British Institute of Archaeology at Ankara, 1974): 13.

remember that the walls and the superimposed paintings needed to be removed in order to continue the excavation and interpret the site.

Having long recognized the deleterious effects caused to archaeological sites by the excavation process, world attention has become increasingly focused on site preservation. Over the past three decades, a series of international symposia and conferences have been held in order to collect and disseminate information relating to strategies and techniques for preservation.[33] The consensus regarding archaeological structures is that every effort should be made to preserve them *in situ*.

Since the 1960s, many conservators have focused their research on the chemical consolidation of archaeological earthen remains.[34] Working with chemical treatment on an archaeological site, far removed from a controlled laboratory setting, can be problematic. Consolidants are often irreversible, and generally have had limited success on exposed earthen structures. Their use is still controversial. Often due to environmental conditions on site, the consolidants may not penetrate the material deeply enough or may not fully polymerize due to relative humidity and temperature extremes. While research continues to progress in this realm, other immediate protective measures need to be researched.

[33] Included among the list are: *2nd and 3rd International Symposia on the Conservation of Monuments in Mudbrick* (1976,1980), both held in Turkey. See bibliography for a more complete list of titles.
[34] Giacomo Chiari is perhaps the most notable proponent for the potential of using chemical consolidants to treat earthen structures. In 1990, he had the opportunity to reevaluate some of his own work, which was applied twenty years earlier, in "Evaluation of the Preservation Work on Earthen Architecture Done in Iraq in the Years 1969-71." *Mesopotamia* 25 (1990): 217-227.

Although it has become commonly recognized that excavation under some sort of shelter does help reduce thermal shock and slow down moisture loss due to surface evaporation caused by sun, and erosion caused by rain, snow and wind, the following alterations have not been systematically addressed: stabilization and monitoring of moisture content, loss of surface pressure, and air circulation. Thus, damage due to rapid drying out still occurs. Another method to reduce the destabilizing effects of excavation is to leave a protective layer of soil on the surface. The soil acts as a sacrificial layer to slowly evaporate water and to hold and isolate the soluble salts. It also provides support as a planar layer or in association with structural buttressing. Such a system was used in the excavation of a frescoed wall in the Crypta Balbi, Rome.[35] The soil assisted in the gradual transition from the fairly constant humidity of the ground to the variations of the open air.

Due to the importance of the plastered mudbrick walls at Çatalhöyük and the possible presence of mural paintings, one must look at all preventive conservation options to protect the site. The site is currently being excavated under temporary, tented shelters. To further alleviate damage, a five centimeter protective layer of soil is left on walls and floors. While this decision helps slow down the rate of drying of the walls and collects the soluble salts which migrate to the surface as the moisture evaporates, it is still limited in its application. The current excavation process does not address what happens to the walls when they inevitably need to be exposed for study, documentation and

[35] Andreina Constanzi Corbau, "Excavated Wall Plasters: Conservation Problems," in *Preventive Measures During Excavation and Site Protection: Conference, Ghent, 6-8 November, 1985.* (Rome, ICCROM, 1986).

prolonged conservation treatments on and off site. Ideally, the walls should be exposed for as short a period as possible and then protected. Based on a materials analysis of the walls at Çatalhöyük, this thesis researches the development of a protective system that practically meets the needs of the excavation process, both in the short and long-term.

3.0 Research Protocol

As already discussed in the previous chapter, severe deterioration of earthen architectural materials in archaeological sites occurs immediately upon excavation. The destabilization of the environment through the removal of a protective earth covering causes a loss of surface pressure and rapid drying of the walls. The result is the migration of soluble salts to the surface, shrinkage cracking, flaking and detachment. An *in situ* protective system should effectively mitigate such damage by slowing down the process of evaporation, gradually allowing the plastered mudbrick walls to reach a state of equilibrium with the ambient conditions. It is the intent that such a system will prevent the rapid desiccation that appears to be the primary cause of the deterioration of earthen walls and paintings at Çatalhöyük due to shrinkage and salt formation of the plastered surfaces. These mechanisms alone, or in conjunction with compromised mechanical strength from root growth and animal burrowing, account for the major immediate problems of preservation at the site.

3.1 Methodology

Before one can intervene by implementing a system of mitigation, such as slowing down the drying rate of the walls, one needs to understand the properties of the materials and the mechanisms of decay involved. A simulation model, useful as a tool for investigation, can only be created after careful planning. Research for this project included a literature survey of similar problems and solutions, on-site sample gathering of

wall cores and moisture readings, characterization and analysis of samples, and laboratory mock-ups of earthen walls for treatment evaluation.

3.2 On-site investigation

Because the main concern of this research, to create a protective site system to retard the rate of evaporation, is based on the premise that rapid evaporation is damaging, and yet controllable, it was necessary to first determine the moisture content on site at various locations in the walls. To help confirm that the drastic differences in the conditions of walls recently excavated versus those previously excavated and left unprotected were related to the rapid evaporation of the surfaces, composition and moisture content were determined and compared in walls excavated by Mellaart thirty years ago and to those by Hodder during the current excavation.

Using a generator-powered hand drill, eleven six-inch core samples were removed from various locations of four selected walls at Çatalhöyük on August 21, 1997. Walls were selected according to parameters considered critical to the moisture problem: length of time exposed (freshly excavated, previously excavated), wall context (freestanding, adjacent to fill), wall thickness (single-width, double-width), wall location (base, middle, top of wall elevation), through-wall location (at surface, interior). Each core was longitudinally divided into one-inch segments in order to measure the progressive moisture content from the surface to the interior of the wall. Thus, 66 samples were analyzed. The purpose was to compare the moisture content of the newly exposed walls versus walls excavated and left exposed thirty years ago.

The west and north walls of Mellaart's Shrine 1 were chosen as examples of exposed walls, left unprotected, for thirty years. Samples from the North Area of the East Mound, Space 71, Building 1, walls F7 and F3 were selected as examples of recently exposed walls.[36] These samples were taken from an area that is being excavated under a tent, sheltered from the direct effects of the sun. All of the samples were taken mid-day, at the period of maximum evaporation of moisture from the walls. As surface evaporation was expected to be greatest at this time of the day, six samples taken at one-inch intervals into the wall were removed to record the change of moisture content from the interior of the wall to the surface. Three sample locations--at the base, middle and top-- were chosen from each wall to reflect potential differences in water source such as rising damp (base of wall), falling damp (top of wall), and adjacent fill (middle of wall).

3.2.1 Sample Location

The west wall of Shrine 1 is an unsheltered seven-foot high single-width wall, backed by unexcavated fill. A core was taken six inches from the base (IA1-6), at the middle (IB1-6), and six inches from the top (IC1-6). The top foot of the wall is exposed on both sides. Samples IC1-6 were taken from an area where the wall was exposed on both sides. Sample IB1 was the only one with plaster remains.

The north wall of Shrine 1 represents an unsheltered double-width wall with fill in-between. The north wall abuts a wall of an adjoining building. Again, cores were taken near the base (IIA1-6), at the middle (IIB1-6) and near the top (IIC1-6) of the wall.

[36] The area names used are those assigned by the field excavators.

Figure 1. Sample locations from Mellaart Shrine 1.

As mentioned above, Space 71 in the North Area was chosen as an area to take samples because it was recently excavated and sheltered. The third series of samples was taken from Wall F7. This wall measured 20" high and 13" wide. Each brick measured about 3" (8cm) high. The first core (IIIA1-6) was taken three inches from the base. The second core (IIIB1-6) was taken near the middle of the wall. The third core (IIIC1-6) was taken three inches from the top of the wall. A fourth core (IIID1-6) was taken from an adjacent mortar joint for comparison.

A final core (IVA1-6) was taken from Wall F3 of Space 71. Wall F3 represents a single-width, freestanding wall. This was the only area from which a sample was taken with a full sequence of painted plaster layers on the mudbrick substrate. This was also the most recently excavated area. Samples were taken less than a week after this area was excavated.

Figure 2. Coring drill with custom attachment and core locations, Wall F7.

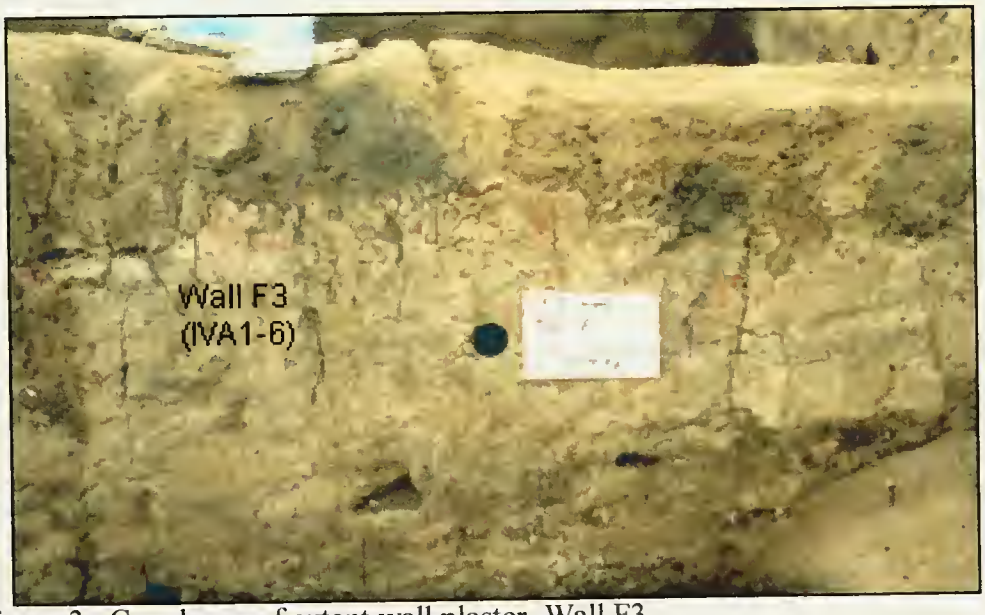

Figure 3. Cored area of extant wall plaster, Wall F3.

Figure 4. General view of sheltered area, Space 71 in the North Area.

3.2.2 Sampling Technique

Samples of each core were taken at one-inch intervals, holding the drill perpendicular to the wall. Each sample was tapped out of the drill into pre-weighed and labeled plastic zip-lock bags to minimize moisture loss. Once weighed, the bagged samples were put in a sealed plastic container to await a customs clearance.

Upon arriving at the Architectural Conservation Laboratory (ACL) of the University of Pennsylvania, each sample was again weighed, oven dried for 24 hours, and weighed again to determine the moisture content. Fortunately, the samples were reweighed. Since each sample appeared to have gained some weight in transport, it was apparent that the electronic scale at the site was not properly calibrated. A Denver Instrument® model XE-510 electronic balance (accuracy +/- 0.01g) was used to measure the samples in the ACL. This instrument was calibrated with a Denver Instrument®

400g weight. Although the recorded percent moisture content for each sample cannot be guaranteed as accurate due to the possibility of slight moisture loss during storage and transportation, they can be used to illustrate the relative moisture curves at various site conditions.

3.2.3 Observations

Some very clear patterns emerge from the data. Wall context seems to play an important role in determining moisture. As expected, the exposed walls of the Mellaart area had very low moisture content at the surface in comparison to the surfaces of the recently exposed walls of the North Area. In every situation, the moisture content was lower on the surface, increasing with depth into the walls. The overall moisture contents were higher at the wall bases than near the top. This is likely due to groundwater sources. The moisture content was lowest near the tops of the walls. This was particularly evident in core sample IC1-6, which was taken from the section of freestanding wall near the top of Shrine I West Wall. This section experiences surface evaporation on both wall faces. Capillary rise of moisture does not appear to be a major factor.

While there are obvious differences in moisture levels when comparing exposed areas to those that are sheltered, patterns also begin to emerge within each area. While the West and North walls of Shrine I have similar moisture contents, the West Wall has a noticeably higher moisture content further into the wall. The increased moisture content

of the West Wall may in part be attributed to groundwater retention in the adjoining unexcavated fill.

The moisture data are presented as Figures 1-4 on the following pages:

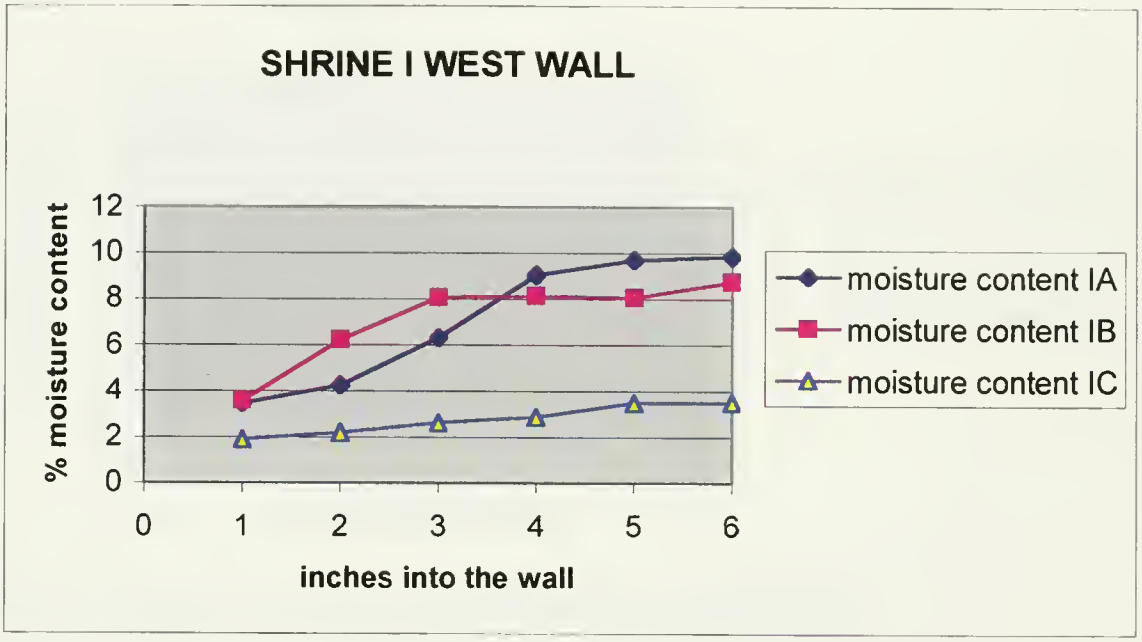

Figure 5. Mellaart Area, exposed for thirty years, backed by unexcavated fill.

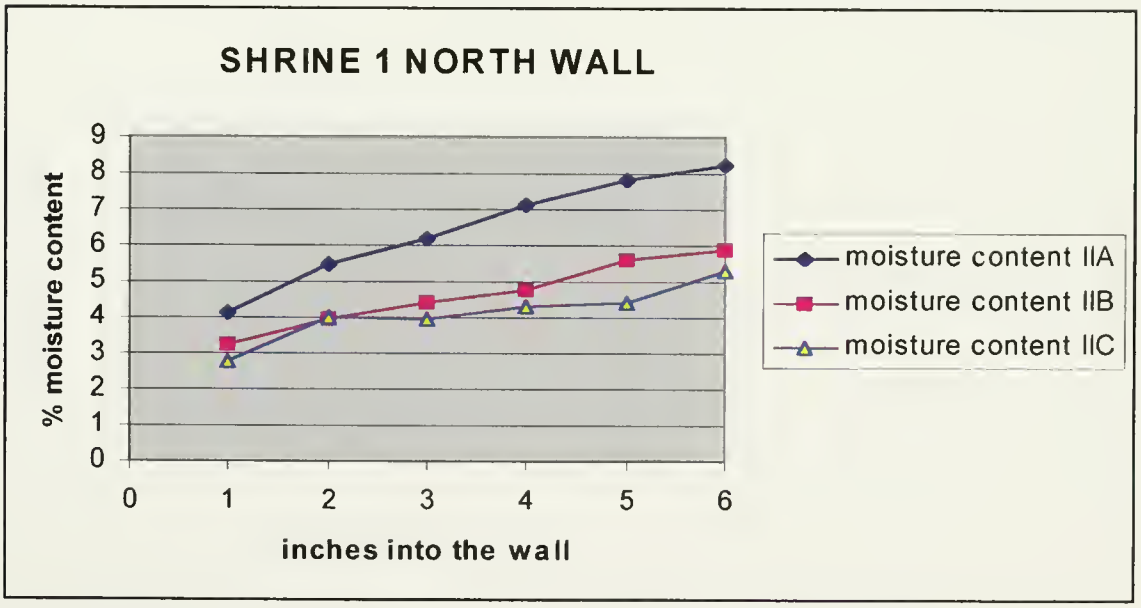

Figure 6. Mellart Area, exposed for thirty years, double-width wall with fill in-between.

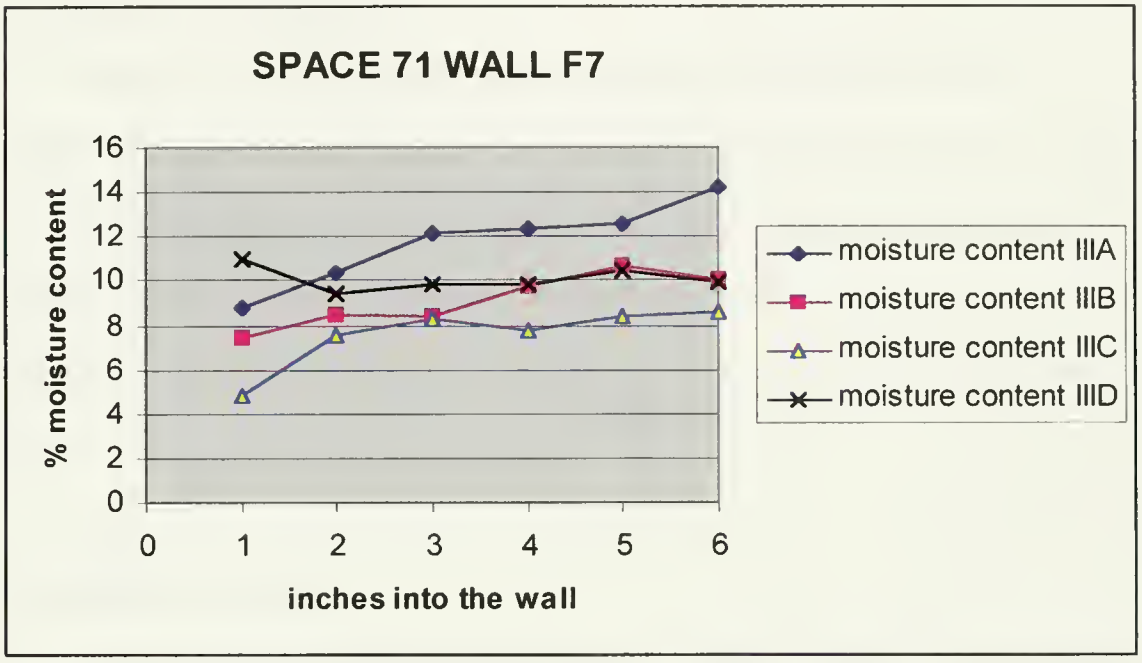

Figure 7. North Area, recently exposed, backed by unexcavated fill.

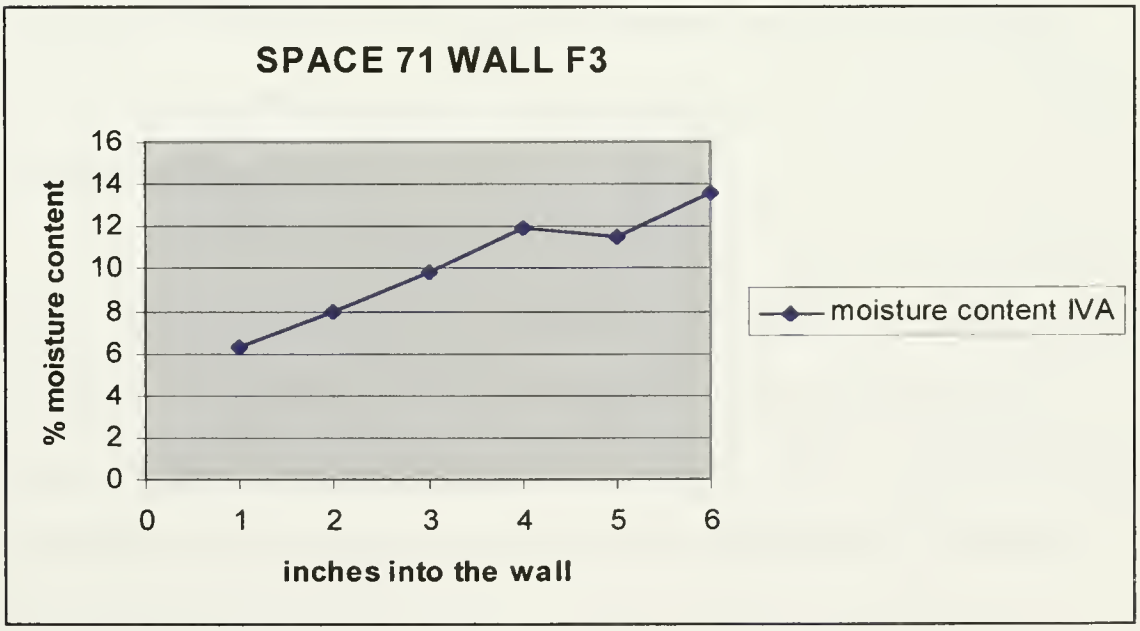

Figure 8. North Area, recently exposed, single-width, free-standing wall.

3.3 Wet Chemical Analysis

Samples were characterized following standard tests adapted for earthen materials. All tests were performed in the Architectural Conservation Laboratory (ACL) at the University of Pennsylvania. The material used was a combination of the samples collected for moisture content analysis in August 1997, as well as a large sample of mudbrick and mortar removed from the Mellaart area of site to the ACL in the summer of 1996.

3.3.1 Soluble Salt Content

Salts on an archaeological site may be from a variety of sources. The weathering of the parent rock is a common source of ions that form salts in soils. Common examples of soil salts include Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2}, and HCO_3^-. The decomposition of animal and human waste produces chlorides and nitrates. Phosphates are a common component of many fertilizers from associated agricultural lands.[37] Maritime sites often have high concentrations of chlorides.

Solid salts are formed when anion and cation pairs reach a critical concentration in water. The critical concentration, or solubility, is reached either by an influx of ions or by evaporation.[38] The capillary movement of water through porous materials is often associated with the deposition of soluble salts at or near the surface. In an archaeological context, excessive salt damage is likely to occur after excavation when the ambient

[37] J.M. Cronyn, *The Elements of Archaeological Conservation.* (New York: Routledge, 1990), 22.
[38] Ibid.

relative humidity (RH) falls and fluctuates.[39] After excavation, the salt solution dries out and crystallizes. If the salt concentration is high enough, the crystals can fill the pores and exert pressure.

Solubility and crystal morphology depend on the particular ions involved. For example, nitrates, chlorides and sulfates have high solubility in comparison to phosphates.[40] Salt build-up, and associated damage, generally occurs at the surfaces of the excavated materials due to the effects of evaporation. When salts crystallize upon evaporation, they experience an increase in volume. In the case of a finished surface, such as the painted plastered walls at Çatalhöyük, salt crystallization often occurs at the surface/substrate interface. The volume increase of the soluble salts causes internal disruptive pressures, jeopardizing the physical integrity of the surface finishes.

It was necessary to test the soluble salts content of the samples from Çatalhöyük in order to determine to what extent, if any, they factored into the decay mechanisms of the plastered walls. Only by knowing how much soluble salt, and which species of salts are in the walls, can one hope to effectively intervene against their destructive natures. Thus, semi-quantitative and qualitative analyses were performed on samples of both brick and mortar from the site.

[39] Ibid., 103.
[40] Ibid., 22.

3.3.1.1 Semi-Quantitative Analyses

Semi-quantitative analyses were performed on a portion of the large sample of mudbrick and mortar removed from site in 1996, as well as samples taken from Wall F3 (IVA1-6) in August 1997. Ground, pre-weighed samples soaked in a beaker of deionized water for 24 hours. Each sample was collected in a #5 Whatman filter paper (catalogue no. 1005 150) while the soluble salts remained in solution. The percent of soluble salts is based on the weight difference before and after soaking and rinsing in the deionized water. Although this method does not indicate which salts there are in specific quantities, it is useful in indicating an overall amount of total soluble salts in the samples.

Since a higher soluble salt content was recorded in mortar that abutted brick of a lower soluble salt content, it is likely that some of the soluble salts were a function of the mortar composition, rather than were introduced as contaminants of the burial soil. The salt contamination at the time of construction is supported by the visible amount of ash and bone inclusions in the mortar, which were not noted in the brick samples. Wood ash is reported to contain sulfates.[41] However, since semi-quantitative analysis cannot confirm which salts are in the sample, further testing was required.

Of the samples tested, the mortar consistently had a higher soluble salt content than did the mudbrick. The total soluble salt content ranged from 4.37%-5.17% for the mortar and from 0.64%-1.48% for the mudbrick of the bulk sample removed from site in

[41] Cronyn, 22.

1996. The soluble salt content of the recent samples (IVA1-6) ranged from 2.15%-3.37%.

The results of the semi-quantitative analysis are given below:

Soluble Salt Content: Quantitative Results				
Sample	**Location**	**$Mass_1$ (grams)**	**$Mass_2$ (grams)**	**% Soluble Salts (M_1-M_2/M_1 x 100)**
Mudbrick (1B)	(from 1996 bulk)	29.67g	29.23g	1.48%
Mudbrick (2B)	(from 1996 bulk)	30.09g	29.72g	1.23%
Mudbrick (3B)	(from 1996 bulk)	29.80g	29.61g	0.64%
Mortar (1M)	(from 1996 bulk)	31.14g	29.78g	4.37%
Mortar (2M)	(from 1996 bulk)	30.68g	29.12g	5.08%
Mortar (3M)	(from 1996 bulk)	32.67g	30.98g	5.17%
IVA-2	(2" into the wall) (from 1997)	17.32g	16.79g	3.06%
IVA-4	(4" into the wall) (from 1997)	26.53g	25.96g	2.15%
IVA-5	(5" into the wall) (from 1997)	19.98g	19.52g	2.30%
IVA-6	(6" into the wall) (from 1997)	20.53g	19.80	3.37%

Table 1

3.3.1.2 Qualitative Analyses

Qualitative analyses were performed in order to identify the presence of specific soluble salts within the mudbrick and mortar samples from Çatalhöyük. Salts tested included: chlorides, nitrates, phosphates, and sulfates. The tests were performed on the filtrates of the semi-quantitative analyses by using microchemical tests. After each ground up sample soaked in a beaker of deionized water for 24 hours, the filtrate was separated into a series of test tubes to test for the presence of the salt ions.

The presence of chloride ions (Cl^-) was tested using two drops of 0.1M silver nitrate, confirmed with three drops of 0.25M lead acetate. Through a simple chemical substitution process, the formation of a white precipitate (either silver or lead chloride) indicates the presence of chlorides.

Sulfate ions (SO_4^{2-}) were tested using two drops of 0.25M barium chloride, confirmed with three drops of 0.25M lead acetate. The formation of a white precipitate (either barium or lead sulfate) indicates the presence of sulfates.

Phosphate ions (PO_4^{3-}) were tested using two drops of 0.1M silver nitrate, confirmed with two drops of barium chloride. Through a substitution process, the formation of a yellow precipitate, silver phosphate, indicates the presence of phosphates.

The presence of nitrates (NO_3^-) was tested by adding two drops of the filtrate to several crystals of iron II sulfate and three drops of concentrated sulfuric acid; a brown color near the crystals indicates a positive. This test is confirmed with one drop of diphenylamine reagent in a 1ml solution of the filtrate; a blue color indicates the presence of nitrates.

The results of the microchemical tests indicated a presence of sulfates and chlorides in all samples. While the tests do not indicate the specific components, both sodium and magnesium sulfates are commonly found in soils.[42] Both phosphates and nitrates tested negative in the bulk sample from 1996. Sample IVA tested positive for phosphates, but negative for nitrates. Based on the amount of precipitate produced upon application of the various chemical spot tests, each of the mortar samples had a more positive reaction to salts than did the mudbrick. Although none were found in the samples tested, one should not be surprised to find areas of high nitrate concentrations at Çatalhöyük since this salt is a common byproduct of animal waste. It is interesting that no phosphates were detected in the bulk sample that was exposed for thirty years, while they were present in the freshly excavated samples. Perhaps three decades of exposure to the effects of weathering eliminated their presence near the wall surfaces.

3.3.2 Acid-Soluble Content

The procedure followed guidelines for performing a gravimetric mortar analysis.[43] Pre-weighed samples of mudbrick and mortar from the large sample removed from site in 1996 were acid digested in a beaker with a 14% (v/v) hydrochloric acid (HCl) solution. After 24 hours, the contents of the beaker were filtered in a #5 Whatman filter paper (catalogue no. 1005 150). The non-soluble material was oven dried and weighed. The

[42] K. H. Head, *Manual of Soil Laboratory Testing, Volume 1: Soil Classification and Compaction Tests.* (New York: John Wiley and Sons, Inc., 1992), 245.
[43] Jeanne Marie Teutonico, *A Laboratory Manual for Architectural Conservators.* (Rome: ICCROM, 1988), Ex. 21, 113-116.

difference of the two weights was considered the acid-soluble content. The results indicated an average acid soluble content of 16.74% for the mudbrick and 17.92% for the mortar. These results are similar to soil reports of the area that indicate a presence of 15%-20% calcium carbonate in all horizons of the marley soil.[44] The results also corroborate previously obtained information.[45] Some of the solublized material may have included shell fragments. The results are presented below:

Acid-Soluble Content: Results			
Sample	**$Mass_1$ (grams)**	**$Mass_2$ (grams)**	**% Acid Solubles**
Mudbrick (I) (1996)	29.33g	24.24g	17.35%
Mudbrick (II) (from 1996 bulk)	29.33g	24.90g	15.10%
Mudbrick (III) (from 1996 bulk)	29.33g	24.12g	17.76%
Mortar (A) (from 1996 bulk)	29.33g	24.15g	17.66%
Mortar (B) (from 1996 bulk)	29.33g	23.74g	19.06%
Mortar (C) (from 1996 bulk)	29.33g	24.33g	17.05%

Table 2

[44] P.M. Driessen and T. de Meester, *Soils of the Çumra Area, Turkey.*(Wageningen: Centre for Agricultural Publishing and Documentation, 1969), 31-37.

[45] Kopelson, "Analysis and Characterization of Architectural Plasters from Çatalhöyük . Turkey," 60. He found that the acid soluble content of the mudbrick was 14.05% versus the 51.98% to 60.05% of the relief and wall plasters.

3.3.3 pH and Conductivity

The pH and conductivity of both the mortar and brick samples were determined using an Omega® pH/Conductivity meter, model PHH-60MS (range 0.00-14.00, accuracy +/- 0.01). The instrument was calibrated with Omega® Buffer Solution 7.00 and Orion PerpHect™ Buffer 10 Solution. The average pH for the brick measured 7.58 and 7.28 for the mortar. These results are consistent with those determined for the plaster.[46] They are also consistent with the soil/geology reports from the area.[47]

The average conductance of the brick samples measured 1206µs and 2930µs for the mortar. Conductance readings can be a useful comparative tool. Although conductivity is not exclusively indicative of the salt quantity in a given material, it is accurate in telling whether one salt reading is greater or less than another. Thus, in this case conductance can be used to confirm that the salt content is greater in the mortar than in the brick.

3.3.4 Sieving and Wet Gravimetric Analysis

Sieving and wet gravimetric analysis by sedimentation was performed in accordance with ASTM D422, "Standard Test Method for Particle-Size Analysis of Soils". Knowing the particle size distribution is an essential component of understanding earthen materials and how they may perform. Three 100g samples were taken from the

[46] Kopelson, "Analysis and Characterization of Architectural Plasters from Çatalhöyük , Turkey," 65.
[47] T. de Meester, *Highly Calcareous Lacustrine Soils in the Great Konya Basin, Turkey,* 11, as cited in Kopelson, "Analysis and Characterization of Architectural Plasters from Çatalhöyük , Turkey," 36-37.

larger bulk sample of mudbrick removed from site in the summer of 1996. The soil was dispersed with a 4% solution of sodium hexametaphosphate to disperse the clay particles. The material was passed through a series of standard-sized sieves. The fine material that passed the 75μm sieve was further characterized through wet gravimetric analysis in a 1000ml glass sedimentation cylinder. After being filled with deionized water and agitated, hydrometer readings were taken at regular intervals in order to plot the distribution of the fine particles.

The testing was based on ASTM's classification of particle size[48]:

Gravel	76.2mm-4.75mm
Coarse Sand	4.75mm-0.75mm
Fine Sand	0.75mm-0.02mm
Silt	0.02mm-0.02mm
Clay	<0.002mm

An average of the results from the three samples is given as follows:

[48] ASTM D422, "Standard Test Method for Particle-Size Analysis of Soils", 04.08.

Particle Size Analysis-Mechanical				
Sieve no.	**Diam. (mm)**	**Wt. Retained**	**% retained**	**% passing**
8	2.36mm	0.31g	0.30%	99.70%
16	1.18mm	0.48g	0.48%	99.22%
30	600μ	4.43g	4.43%	94.79%
50	300μ	4.18g	4.20%	90.59%
100	150μ	7.68g	7.67%	82.92%
200	75μ	3.67g	3.67%	79.25%

Table 3

Of the material analyzed, only 20.75% was sand. The remaining 79.25% of fine material was collected for further wet gravimetric analysis. The results proved similar to that previously performed on the relief plasters.[49] The fines were further divided as approximately 60% silt and 10% clay.

[49] Kopelson, "Analysis and Consolidation of Architectural Plasters from Çatalhöyük ,Turkey," 61-64.

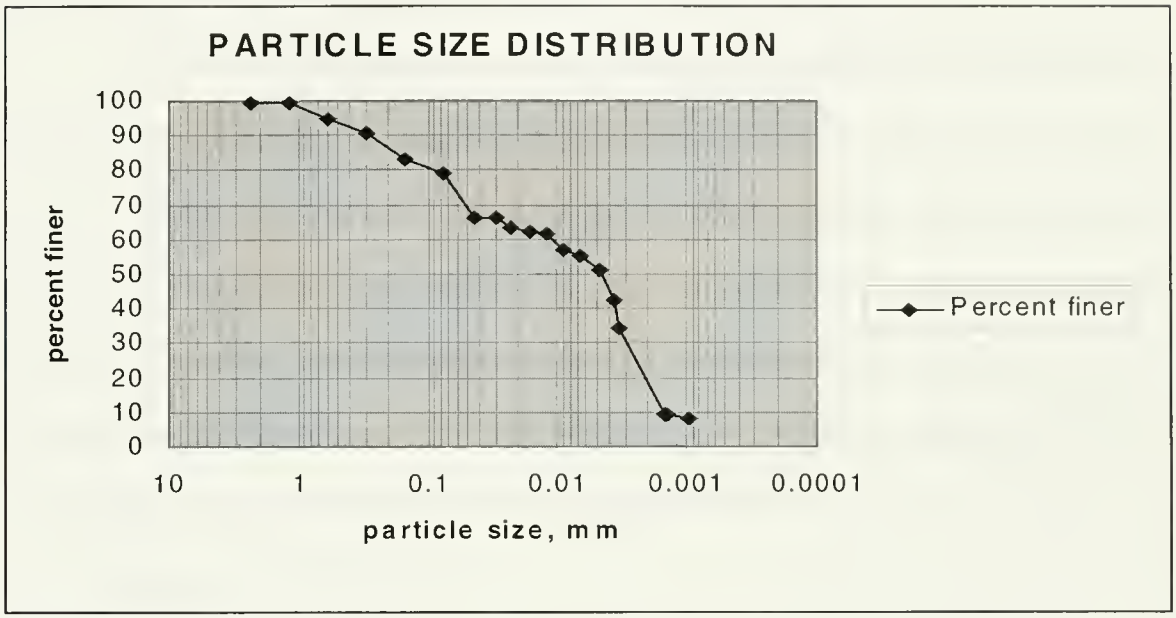

Figure 9

3.4 Tests for Physical Properties

3.4.1 Atterberg Limits

The Atterberg Limits are standards that allow one to measure and describe the plasticity range of a clay soil in numerical terms. The major components of the Atterberg Limits are the plastic and liquid limits of soil. The liquid limit and plastic limit offer insight as to how soils, used in an architectural setting, may respond to water. While granulometry provides information on particle size distribution and the amount of clay present in a soil sample, it offers no direct insight as to the properties of the clay. The Atterberg Limits enable clays to be classified physically.

3.4.1.1 The Plastic Limit

This test was performed in accordance with ASTM D4318-84, "Standard Test for Liquid Limit, Plastic Limit and Plasticity Index of Soils", to determine the lowest moisture content, in percent, of the samples at the boundary between the plastic and solid states. The plastic limit is defined as the water content at which the soil can be hand rolled from threads of 6mm in diameter into 3.2mm threads without crumbling. The first crumbling point is the plastic limit. Four mudbrick samples were selected from the bulk sample that was removed to the ACL in the summer of 1996.

The results are given below:

Plastic Limit				
Sample	**Weight at PL**	**Dry Weight**	**Moisture Wt.**	**% Moisture**
1	9.18g	7.58g	1.60g	17.4%
2	8.73g	7.18g	1.55g	17.7%
3	8.69g	7.18g	1.51g	17.4%
4	8.04g	6.65g	1.39g	17.3%

Table 4

The average plastic limit is 17.5%, ranging between 17.3% and 17.7%.

3.4.1.2 Liquid Limit—Casagrande Device

This test was performed in accordance with ASTM D4318-84 to determine the moisture content, expressed as a percentage of oven-dried soil, at which soil passes from the plastic to the liquid state. The liquid limit is defined as the water content at which two halves of a soil cake placed in a Casagrande device flow together at the base of the groove for a distance of ½ inch when the cup is dropped 25 times from a height of 1cm at a rate of two drops per second. Six samples were tested from the bulk sample that was removed to the ACL in the summer of 1996. The liquid limit was found to be 40.2%.

The results are given below:

Liquid Limit Test—Casagrande Device				
No. of Blows	**Initial Weight**	**Dry Weight**	**Moisture Lost**	**% Moisture**
28	12.22g	10.56g	4.17g	39.5%
25	12.66g	10.97g	4.41g	40.2%
22	12.67g	10.98g	4.49g	40.9%
20	12.15g	10.47g	4.32g	41.3%
15	12.02g	10.33g	4.44g	43%
10	13.46g	11.76g	5.29g	45%

Table 5

3.4.1.3 Plasticity Index (PI) and Coefficiency of Activity

The plasticity index (PI) is the numerical difference between the liquid and plastic limits. It is a measure of the plasticity of the clay within a soil sample. If a soil lacks cohesiveness, its PI is zero. Of the samples tested from Çatalhöyük, the PI was found to be 40.2.

The coefficiency of activity, or colloidal activity, is the relationship between the PI and the clay fraction for a particular clay within a sample. It is expressed as the plasticity index divided by the percent of clay in the sample. Based on the coefficiency of activity, clays can be classified into four groups:

Description	Activity
Inactive clays	<0.75
Average activity	0.75-1.25
Active clays	1.25-2
Highly active clays (i.e. smectite)	>2

Table 6

The coefficient of activity for the clay component of the mudbrick samples tested from Çatalhöyük is 2.5. This figure corresponds to the category of highly reactive clays. This result agrees with a local geological survey that identifies smectite, a highly reactive clay,

as a major component of the soil.[50] It is also in accordance with the observed swelling of the samples on site and in the lab.

3.4.2 X-Ray Diffraction (XRD)

To confirm the specific reactive clay within the mudbrick samples, x-ray diffraction (XRD) was performed at the Laboratory for Research on the Structure of Matter (LRSM) at the University of Pennsylvania. XRD is an analytical method of identifying crystalline compounds within a material. The mechanism measures the diffraction of x-rays as they pass through the crystal lattice of a material. Because each material has a unique crystal lattice, all materials have specific XRD patterns The angles of diffraction are represented by a series of peaks plotted on a chart.

In order to limit the number of peaks, and thus facilitate interpretation, only the fines collected in the sedimentation cylinder were used. About a gram of material was ground to a fine powder and placed on a vaseline-coated glass slide. Because it is difficult to identify reactive clays based purely on elemental analysis, the sample was run a second time after being glycolated.[51] Since smectite has weakly bonded platelets, in theory, one should be able to expand the distance between them. Ethylene glycol, a very bipolar material, was chosen.

A second sample was saturated in a sealed Pyrex® petrie dish with ethylene

[50] P.M. Driessen and T. de Meester, *Soils of the Cumra Area, Turkey*, 31-37.
[51] Technique explained and described in the following: Pierre Biscaye, "Mineralogical and Sedimentation of Recent Deep-Sea Clay in the Atlantic Ocean and Adjacent Seas and Oceans," *Geological Society of America Bulletin* 76 (New York: Geological Society of America, 1965): 803-832.

glycol vapors. Since the ethylene glycol only affects the reactive clay, if it is present, the XRD results of the two samples were compared. For both the dry and ethylene glycol treated samples, 50% of the material was composed of silicon oxide (quartz) and 35% was calcium carbonate. The remaining 10% that XRD was able to detect was identified slightly differently in each sample. The clay component of the untreated sample was identified as potassium aluminum silicate hydroxide hydrate, whereas the clay component of the glycolated sample was identified as sodium magnesium aluminum silicate hydroxide. The two results were based on the different distances, or d-spacing as calculated from Bragg's Law,[52] between the clay platelets. Since non-reactive clay would not be effected by the ethylene glycol, the XRD analysis confirms the presence of reactive clay as in the mudbrick from Çatalhöyük.

[52] Bragg's Law: $\lambda=2d\sin\theta$. This formula explains why cleavage faces of crystals appear to reflect x-ray beams at certain angles of incidence (θ). The variable d is the distance between atomic layers in a crystal; the variable λ is the wavelength of the incident x-ray beam.

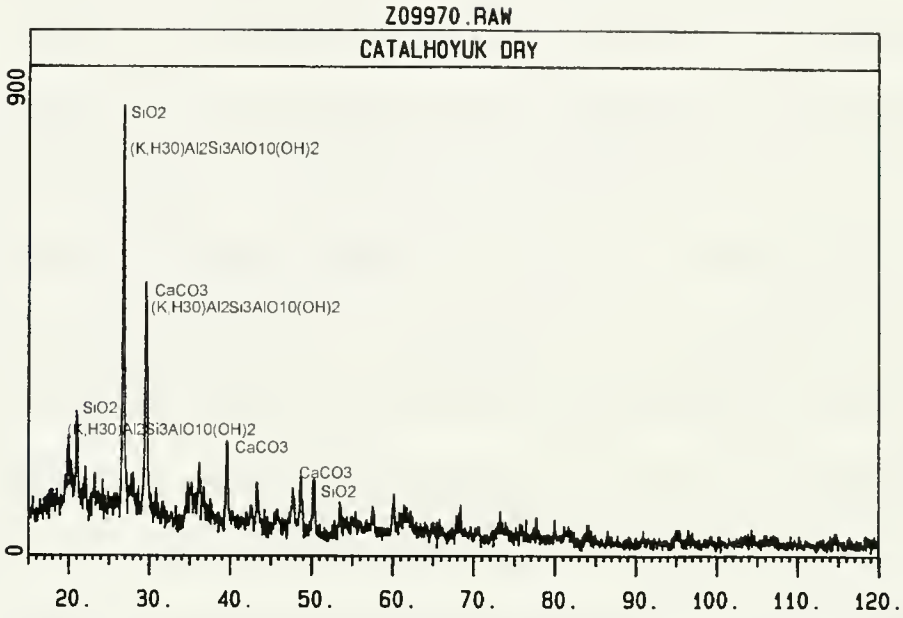

Figure 10. X-ray diffraction peaks of untreated sample.

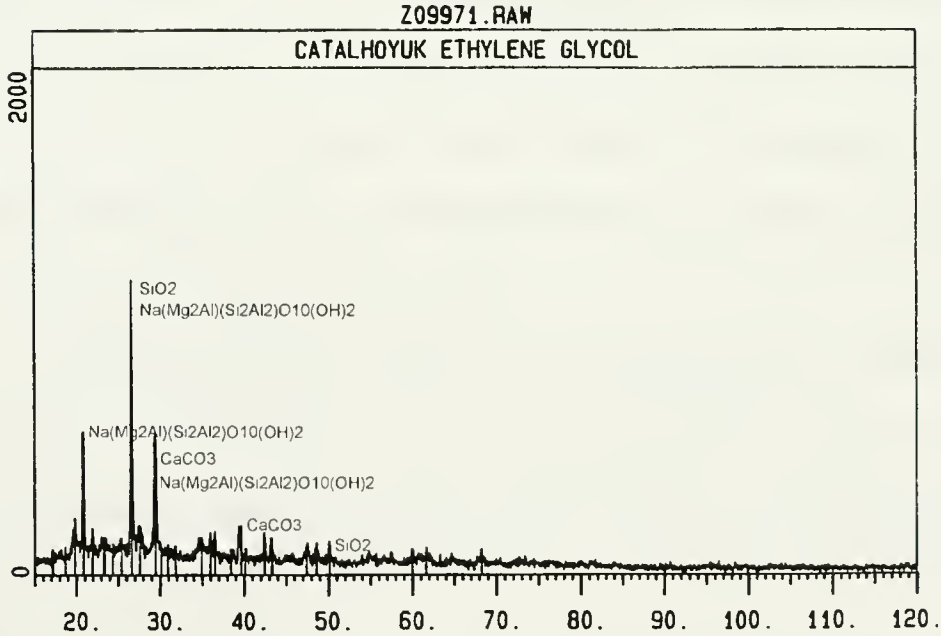

Figure 11. X-ray diffraction peaks of glycolated sample.

3.4.3 The 3-Point Modulus of Rupture and Flexural Strength Test

This test was performed in accordance of ASTM D1635. The purpose of the test is to measure both the load required to break a sample, as well as the flexion under loading before failure. On November 12, Dr. Alex Radin of the Laboratory for Research on the Structure of Matter (LRSM) at the University of Pennsylvania tested eleven samples measuring 3" by 1" by 1" on an Instron 1331 Testing Machine. The samples of mudbrick were taken from the large wall section removed to the ACL in the summer of 1996. Two blades, spaced 2" apart, supported each sample. A suspended central blade applied load to the samples at their midpoint until they broke.

The results were plotted with displacement (0.005") on the x-axis and by load (up to 25lbs) on the y-axis. The result of displacement measures the flexural strength, or brittleness of a sample. Most of the samples cracked at a load of between 14 and 25 pounds. Two of the samples exhibited micro-cracks before they failed. The first sample displayed more flex before failing than the other samples. This is unlikely an anomalous condition, but rather the result of poor sample preparation. In order for the results to be accurate, the samples must have parallel edges.

In simple terms, the results indicate that at ambient laboratory conditions (RH 30%, 68°-70° F), the dry material is very brittle and not particularly strong. The results are in accordance with general findings that soils with high clay contents produce adobe with low flexural strength.[53]

[53] R. Clough, *Qualitative Comparison of Rammed Earth and Sun Dried Adobe Brick*. (Albuquerque: University of New Mexico Press, 1950).

The results are given below:

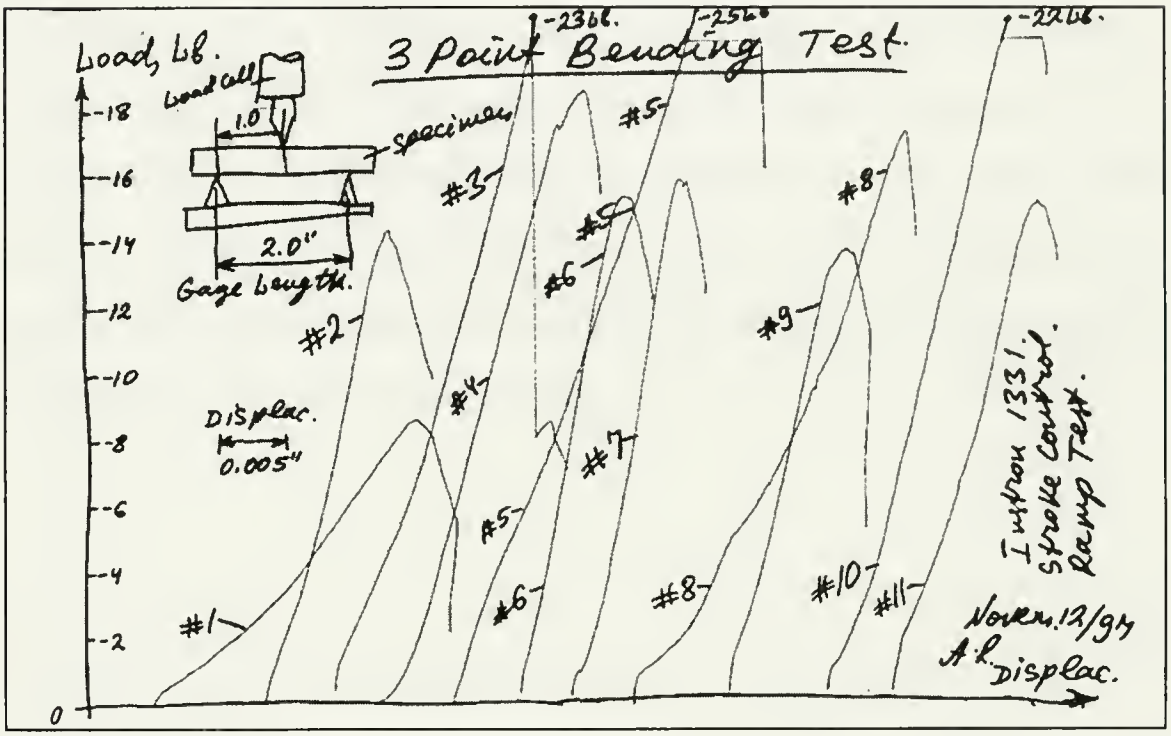

Figure 12. Print-out from the Instron 1331 Testing Machine.

3.4.4 Specific Gravity

This test was performed in accordance with ASTM D2726, "Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens". In preparing a comprehensive conservation plan for Çatalhöyük, one must acknowledge the possibility of removing wall sections from site. This test was included in the event that it proves useful in planning the logistics of such removal.

Eleven cubic inch samples taken from the large wall section removed to the ACL in the summer of 1996 were tested. Of the eleven samples, the bulk specific gravity ranged from 1.36g/ml to 1.60g/ml, with an average of 1.54g/ml. The range of results is invariably due to the lack of homogeneity in the samples. Although samples of the same size were prepared, their inner pore structures and inclusions are not identical. Each sample naturally had a different distribution of voids and inclusions. Overall, the results proved similar to those determined by Kopelson for the wall plasters.[54] The average bulk specific gravity for the plasters was 1.53 g/ml.

[54] Kopelson, "Analysis and Consolidation of Architectural Plasters from Çatalhöyük ,Turkey," 236-240.

4.0 Model Simulation Rationale

One primary objective of this thesis is to explore and identify possible temporary protective systems that could be implemented on sections of the plastered walls at Çatalhöyük during the 1998 and future field seasons. As this research was conducted off site, with limited access to materials, scaled wall models (assemblies) were built with materials having similar properties to those found on site. Although conditions identical to those on site cannot easily be replicated, a simulation model is still a useful tool for comparative assessment of different mitigation techniques under controlled situations and variables.

4.1 Wall Assemblies

Based on the soil analysis described in the preceding chapter, three plastered mudbrick wall assemblies were constructed. Each wall was composed of mudbricks, mortar, a plaster scratch coat, and two plaster finish coats, including a painted design layer. An average wall section, measuring 4m wide and 2.5m high, was chosen. This decision was based on the possibility of finding an intact painted surface of this size. In order to practically work with the assemblies, they were built in quarter-scale. Thus, each wall measured 1m wide by 0.625m high.

The assemblies were built in a studio space in the basement of the Fisher Fine Arts Library at the University of Pennsylvania. The relative humidity (RH) was recorded at 34%, with the temperature ranging between 19°-21° C during the experiment.

4.1.1 Mudbricks

Based on visual observation on site, as well as Mellaart's accounts, an average brick size of 80cm in length, by 28cm in width, by 8cm in height, was selected as representative. A total of 214 bricks were made in wooden molds. The composition was based on the results of the gravimetric analysis of samples taken from the site (see 3.3.4, Table 3). For the replicate bricks, the only criterion for sand selection was that it conform to the correct particle size distribution. Particle shape was not addressed. A variety of sand was obtained from local suppliers. The sand was sieved to conform to the particle size distribution of the Çatalhöyük samples.

The remaining 79.25% accounted for the silt and clay portion of the mudbricks. This was filled with bentonite clay. Based on earlier research, this clay was chosen because of its high reactivity and availability.[55] Although straw-like impressions were visible in the original samples, no fibrous organic binder was added in the replicate bricks. This decision was based on the assumption that any original organic additives had long since decomposed and were not likely to be encountered upon excavation. In addition, no lime (calcium carbonate) was added to the bricks.

The bricks were dry-mixed six at a time. They were then mixed with a Hobart C-100 paddle mixer according to ASTM Standard C305, "Test Method for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency". A 4% sodium sulfate solution was added to each batch to introduce soluble salts into the wall as

[55] Catherine Turton, "Plan for the Stablilization and Removal of Wall Paintings at Çatalhöyük ," (master's thesis in Historic Preservation, University of Pennsylvania, 1998).

observed on site. The bricks dried slowly in the molds for several weeks. After experimenting with various treatments of the molds (i.e. coating with wax, petroleum jelly), coating them with aluminum foil was found to be the most effective means to facilitate extraction of the bricks. To prevent rapid dessication, the bricks were covered with straw and draped with plastic film.

4.1.2 Mortar

The mortar was based on the same formulation as the mudbricks. However, whereas each brick was composed of about 80% bentonite clay, the mortar was composed of 65% clay and 15% hydrated lime. While the replicate mortar and the mudbrick could have been made of identical composition for laboratory-testing purposes, the substitution of 15% hydrated lime was based on time constraints. As the assemblies were being built, it became apparent that there would not be enough bentonite clay to complete the walls. Rather than completely stop production while awaiting a new shipment of clay, the hydrated lime was added. This decision justified itself based on the acid soluble content of the original material (see 3.3.2, Table 2).

As with the mudbricks, the material was dry-mixed first, before adding the water. Enough mortar was mixed to lay three rows of mudbrick at a time. A decision was made not to add a salt solution to the mortar. While it was the intention to approximate conditions on site, the researcher was wary of intrinsically inducing too much damage in the walls, which could result in their total failure before the testing program was completely set up.

4.1.3 Plaster Base Coat

The composition of the plaster base coat is the same as what was used earlier in previous research.[56] About 10% of the material was composed of sand, 50% of hydrated lime, and 40% of bentonite clay. Bentonite was chosen for its reactive properties similar to the smectitic clay from the site.

The mudbrick/mortar wall was wetted before the application of the several millimeter-thick base coat. The wall was then covered with plastic sheeting to retard drying, with the hope of preventing shrinkage cracks. After 24 hours, the base coat exhibited extensive alligator cracking. The surface was thoroughly misted and vigorously manipulated. It was again covered in order to dry slowly. After another 24 hours, the walls displayed substantially fewer cracks. This was attributed to manipulation during application, and a slower drying rate. Based on this simple laboratory observation, it is likely that the plastered walls at Çatalhöyük were burnished during application to minimize cracking.

4.1.4 Plaster Finish Coat

The composition of the plaster finish coat is virtually identical to that of the base coat. The only difference is that 3% sand and 47% clay was used. The remaining 50% comprised hydrated lime. As with the base coat, a thin layer was applied by hand to a damp wall. A decorative pattern was brush applied to the first finish coat, painted

with black and red water colors, and then plastered over with a final unpainted layer. The purpose was to help ascertain whether failure of the plaster system was total, or whether it was interlayer.

Figure 13. Applying final finish coat on top of painted plaster layer.

4.2 Model

Three supportive wooden frames were built to contain each wall assembly. Each frame is 86cm wide, 60cm high, and 10cm deep. In order to isolate the evaporation front of the walls, each frame was enclosed on five sides. To prevent moisture loss through the wooden frames, each interior face was coated with plastic film. The idea was to approximate overall site conditions. Upon excavation, the plastered surfaces generally

[56] Turton, "Plan for the Stabilization and Removal of Wall Paintings at Çatalhöyük." She, in turn, based her particle size distribution on Kopelson's results, "Analysis and Consolidation of Architectural Plasters from Çatalhöyük ,Turkey," 62-64.

are exposed while the rest of the wall is surrounded by unexcavated fill. Once the basic frames were assembled, they were attached to four foot by two foot wooden bases. For further support, each frame was buttressed on the back and the sides.

After the frames were built and sealed with plastic sheeting, a series of holes were drilled in the rear wooden backing. The holes were placed at regular intervals so that water could be introduced from behind. The intention was to control and maximize the moisture content prior to the start of testing. To prevent evaporation from the rear of the assemblies, the drilled openings were plugged with corks.

Once the frames were complete, the mudbricks sufficiently cured, and the mortar mixed, the walls were built.[57] The scratch and finish coats sealed the water channels on the wall surface. While not based on archaeological evidence, the bricks were laid in common bond. This pattern was selected as it could be easily duplicated on each wall assembly. The spacing of common bond also facilitated the regular placement of the drilled water channels in the mortar joints. Each row was composed of four bricks.

4.3 Protective System

A protective system was designed to practically meet the needs of the excavation, and to be in accordance with the resolutions and recommendations from the International

[57] Although three frames were built, due to time constraints, only two complete wall assemblies were constructed and tested.

Symposia on the Conservation of Monuments in Mudbrick.[58] The main objectives of the system were that it be temporary and modular, and be made of affordable, readily available materials. Other requirements were that it control the loss of moisture while minimizing air circulation and reducing the loss of compression. Because excessive surface moisture loss is experienced immediately upon exposure from excavation, the system is to be put in place as soon as the plastered walls are exposed.

4.3.1 Backfilling

The protective system is based on the concept of backfilling archaeological sites for long-term protection against exposure after excavation. Backfilling, while reversible, is generally considered a final method of site preservation. While the premise of back-filling a site is to preserve it, one must remember that it is a drastic decision for an archaeologist. Once the backfill material is in place, the site is no longer accessible for interpretation or further documentation.

One also needs to be aware that there is no consensus as to the overall success of backfilling. While everyone agrees that backfilling is performed to preserve a site from accelerated weathering, and sometimes vandalism, caused by exposure, there is an open discussion as to which materials to use and how to maintain them. While there has been relatively little research assessing the efficacy of backfilling, what has been published does illustrate that the choice of material is of importance. One needs to select materials that will not induce further damage. For example, sea sand should not be used at

[58] See Appendix A for the resolutions and recommendations.

maritime sites because of its high soluble salt content. Materials used for backfill should allow the passage of water vapor, while minimizing the flow of liquid water. An ideal backfill material should also provide adequate insulation against freeze-thaw cycles.[59]

While conservators agree that backfilled areas should be checked regularly for damaging effects of settling, erosion, and plant or animal infestation, there is little evidence that this occurs.[60] Once a site, or large area of a site, is backfilled, one generally assumes that it is protected. There has not been a trend to re-excavate back-filled areas to determine if such a system does in fact provide adequate protection in relation to the materials and time used for its implementation.

While the rationale behind backfilling, to stabilize exposed structures against the effects of loss of pressure, and fluctuations in relative humidity and temperature, is commendable to try and ensure long-term *in situ* preservation, unfortunately, backfilling does nothing to protect against immediate damage caused upon excavation. As demonstrated at such earthen sites as Çatalhöyük, it is within the first days, or even hours, that the plastered wall surfaces experience irreparable damage resulting from rapid dessication. Thus, a system is needed to be put in place to protect wall surfaces during the excavation process. Such a system needs to be flexible to conform to irregularities of walls and plaster relief sculptures. Whether it is draped over the wall or applied with such surface pressure as sandbagging, the system must be easily and quickly installed and

[59] Cronyn, 123.
[60] Paolo Mora. "Conservation of Excavated Intonaco, Stucco and Mosaics." In *Conservation on Archaeological Excavations.* (Rome: ICCROM, 1984), 105. Catherine Sease. *Conservation Manual for the Field Archaologist.* (LA: University of California, 1987), 117.

removed for inspection and discussion of the eventual outcome of the particular wall surface in question.

4.4 Selection of Materials

In order to mitigate the deleterious effects of rapid drying of the walls, a protective system needs to be designed to practically meet the needs of the excavation. The choice of system was based on the results of a literature survey and laboratory testing of various materials. Although material effectiveness was crucial, selection of the final system was also based on availability and cost of material. Due to their reported neutral pH (similar to the soil found on site), general chemical inertness, and absorptive qualities, vermiculite and perlite were selected as candidates for the filler component of the protective system.

4.4.1 Vermiculite

Vermiculite is a material commonly cited for use as a backfill material of archaeological sites because of its absorptive qualities. Both Mora and Sease recommend using vermiculite to backfill wall paintings, as other materials may be too hard or sharp to be placed against plaster surfaces.[61]

Vermiculite is the mineralogical name given to hydrated laminar magnesium-aluminum-ferrosilicate tetrahedral clay minerals. It is a monoclinic phyllosilicate with a

[61] Ibid.

continuous network of silicon tetrahedra. Vermiculite is composed of two planes of oxygen and hydroxyl with silicon in the tetrahedral sites between the anion planes.[62] Layers are bonded together through weak electrostatic bonds or through large interlayer cations.

Vermiculite is commonly formed by the weathering or hydrothermal alteration of biotite. When heated quickly to temperatures upwards of 1000° C, the water between the layers converts to steam pressure that expands the material, increasing its volume 15 to 20 times its original size. See the following table for its mineralogical breakdown:

Element	Percent by Weight
SiO_2	38-46%
Al_2O_3	10-16%
MgO	16-35%
CaO	1-5%
K_2O	1-6%
Fe_2O_3	6-13%
TiO_2	1-3%
H_2O	8-16%
Other	0.2-1.2%

Table 7. Taken from http:www.vermiculite.org/Vermiculite-properties.htm.

[62] William D. Ness, *Introduction to Optical Mineralogy*, 2nd. Ed. (New York: Oxford University Press, 1991), 241.

Vermiculite is characterized by a high water-holding capacity because of its large surface area. It has a low bulk density, nearly neutral pH, and a high cation exchange capacity. Because it compacts readily when combined with heavier materials, industry does not recommend its use for container media. For packing purposes, vermiculite should be mixed with other materials such as perlite to maintain sufficient porosity and volume. As the internal structure deteriorates, air porosity and drainage decreases. Vermiculite can adsorb phosphates, but cannot absorb nitrates, chlorides or sulfates.

Vermiculite is manufactured in four different grades, differentiated by particle size. The particle size influences the water-holding capacity and aeration porosity of the material. Grades consisting of larger particle sizes have a higher aeration porosity and lower water-holding porosity than grades consisting of smaller range of particle sizes.

See the following table for the properties of the four vermiculite grades:

					Water Retention	
Grade	Bulk Density (kg/m^3)	U.S. Sieve Size	Particle Size (mm)	Aeration porosity (%)	% weight.	% volume
1	64.1-112.1	3/8-16	1.2-10	44.3	297	30.7
2	64.1-128.2	4-30	0.6-4.7	40.4	412	39.0
3	80.1-144.2	8-100	0.1-2.4	29.9	530	52.4
4	96.1-176.2	16-100	0.1-1.2	24.5	499	54.4

Table 8. Taken from the Dept. of Floriculture and Ornamental Horticulture, Cornell University.

4.4.2 Perlite

Perlite is an isotropic alumino silicate mineral of volcanic origin. It is produced by hydrating rhyolitic glass.[63] One of the world's leading producers of perlite is Turkey. The processing includes heat treatment of up to 1000° C. As with the processing of vermiculite, the internal water escapes as steam, resulting in the expansion of the material. It expands many times its original volume to form lightweight white particles containing small internal pockets of sealed gases.

See the following table for perlite's mineralogical breakdown:

Element	Percent by Weight
Oxygen	47.5%
Silicon	33.8%
Aluminum	7.2%
Potassium	3.5%
Sodium	3.4%
Water	3.0%
Iron and calcium	0.6%
Magnesium and trace elements	0.2%

Table 9. Taken from Tech. Data Sheet 1-1, Perlite Institute, New York, 1983.

[63] Nesse, *Introduction to Optical Mineralogy*, 2nd Ed., 267.

Perlite is characterized by its neutral pH, low cation exchange capacity, and low water-holding capacity. Most of the water is held superficially either by surface cavities or between perlite particles. The closed-cell composition of perlite contributes to its compaction resistance.

4.4.3 Water Absorption Tests

Based on the above information, both vermiculite and perlite were viable candidates for further testing as packing materials in the protective system. They meet established criteria by having such properties as neutral pH, water-absorptive capacities, are lightweight and readily available in Turkey. To decide which would be the best packing material, or combination of packing materials, water absorption tests were run and compared to a soil sample from site as the control.

Oven-dried material was weighed in fine mesh bags and immersed in water until total saturation was reached. The weight was recorded at total saturation, and at regular intervals as the samples air-dried in a relative humidity of 34% at 25° C. The samples chosen included soil from site, a 25 soil:75 perlite mix (by volume), a 50 perlite:50 vermiculite mix (by volume), a 25 perlite:75 vermiculite mix (by volume), a 75 perlite:25 vermiculite mix (by volume), 100% perlite, and 100% vermiculite.

The soil absorbed the least amount of water. It also dried to a hard, solid mass. While the mesh bag containing 100% perlite initially absorbed the most water, it also lost it at the quickest rate. Because the protective system aims to slow down the overall drying rate of the walls, a system that releases moisture into the atmosphere too quickly is

undesirable. The bags containing 100% vermiculite and a 25 perlite: 75 vermiculite mix experienced a noticeable volume loss upon drying. Thus, as a packing material, a high vermiculite content was rejected. For a protective system to be effective in providing positive pressure and in minimizing air circulation, the packing material must retain its volume and not settle, creating air pockets near the top. Thus, based on the criteria laid out for a protective system, the most successful mix was the bag containing 75% perlite and 25% vermiculite. This combination initially absorbed the most water, and lost it at a similar rate as the other mixtures. Also critical was its ability to retain its volume without noticeably compacting and settling to the bottom of the mesh bag.

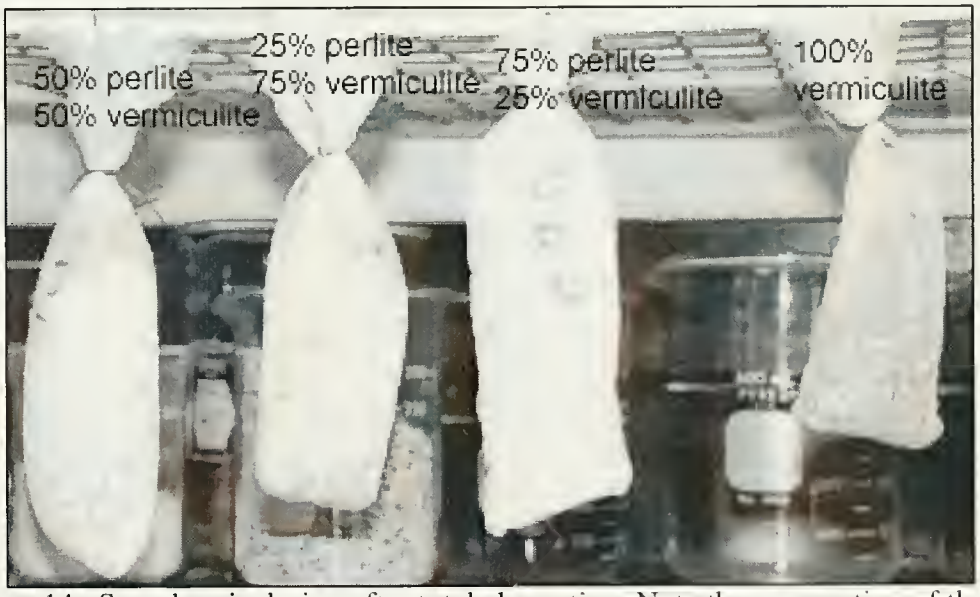

Figure 14. Samples air-drying after total absorption. Note the compaction of the vermiculite.

Based on the water absorption results, the 75% perlite and 25% vermiculite mixture was selected for the experimental testing program. The test results are given as follows:

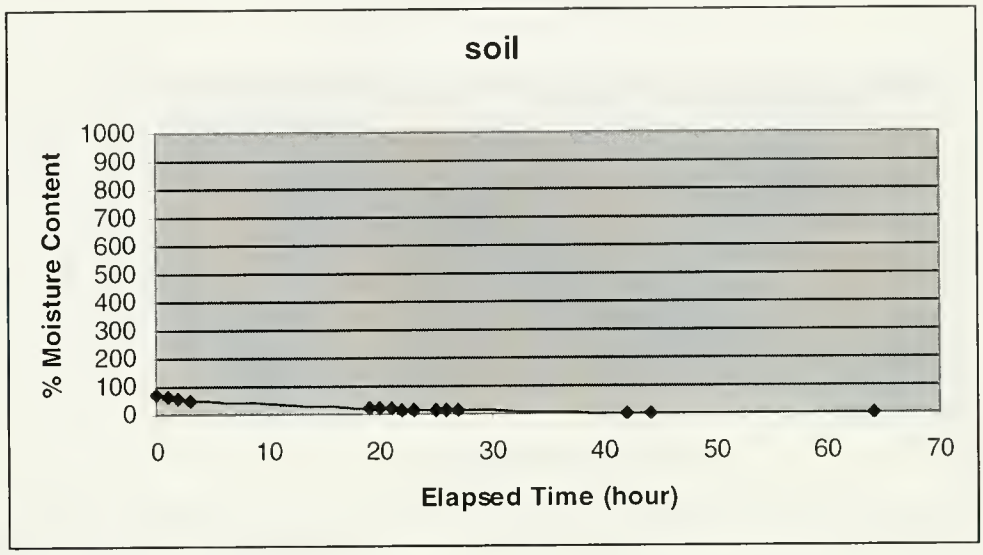

Figure 15. Evaportation curve of soil.

Soil--Initial Dry Mass 34.55g		
Time (hours)	**Sample Mass (grams)**	**% Moisture**
0	60.91	74.27
1	55.69	61.19
2	54.61	58.06
3	52.50	51.95
19	42.46	22.89
20	41.86	21.58
21	41.12	19.02
22	40.67	17.71
23	40.31	16.15
25	39.37	13.95
26	38.82	12.36
27	38.45	11.29
42	34.92	1.07
44	34.81	0.75
64	35.71	0.43

Table 10

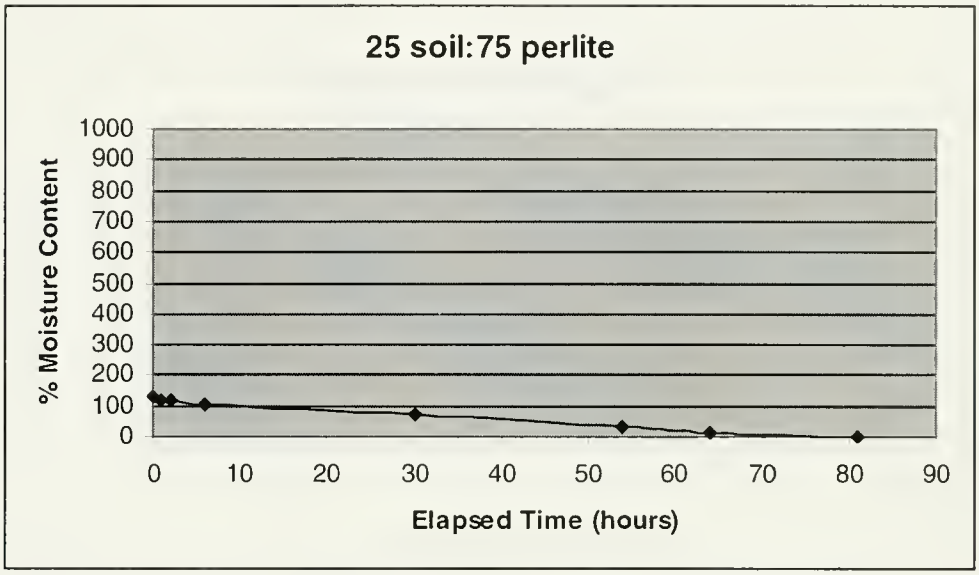

Figure 16. Evaporation curve of a 25 soil: 75 perlite mixture.

25 soil:75 perlite--Initial Dry Mass 69.36g		
Time (hours)	**Sample Mass (grams)**	**% Moisture**
0	160.07	130.78
2	150.22	116.26
6	140.54	102.62
30	117.96	70.07
54	94.35	36.03
64	78.49	12.46
81	68.99	0

Table 11

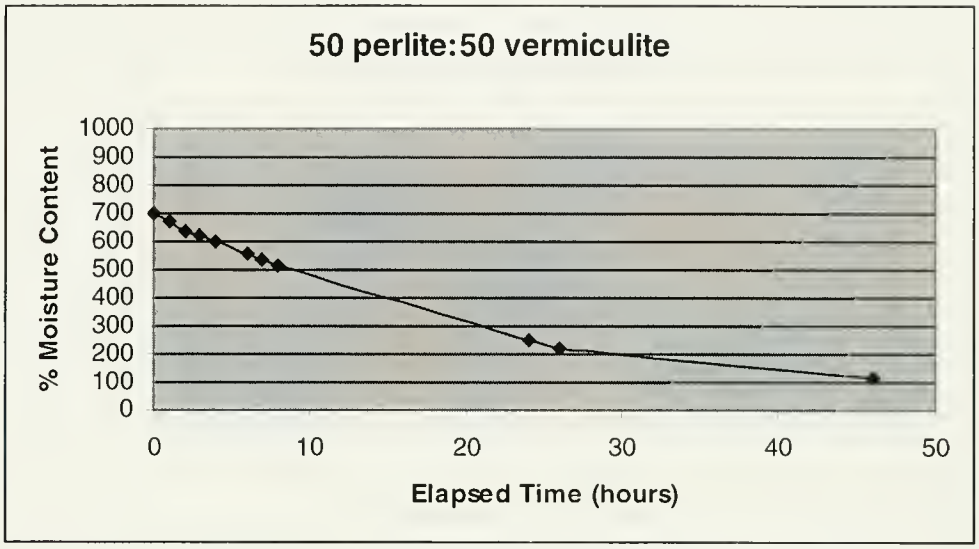

Figure 17. Evaporation curve of a 50 perlite: 50 vermiculite mixture.

50 perlite:50 vermiculite--Initial Dry Mass 9.99g		
Time (hours)	**Sample Mass (grams)**	**% Moisture**
0	79.69	697.50
1	77.05	671.27
2	73.64	637.14
3	71.75	618.22
4	70.13	602.00
6	65.98	560.46
7	63.47	535.36
8	61.62	516.82
24	34.84	248.75
26	31.99	220.22
46	21.49	48.95

Table 12

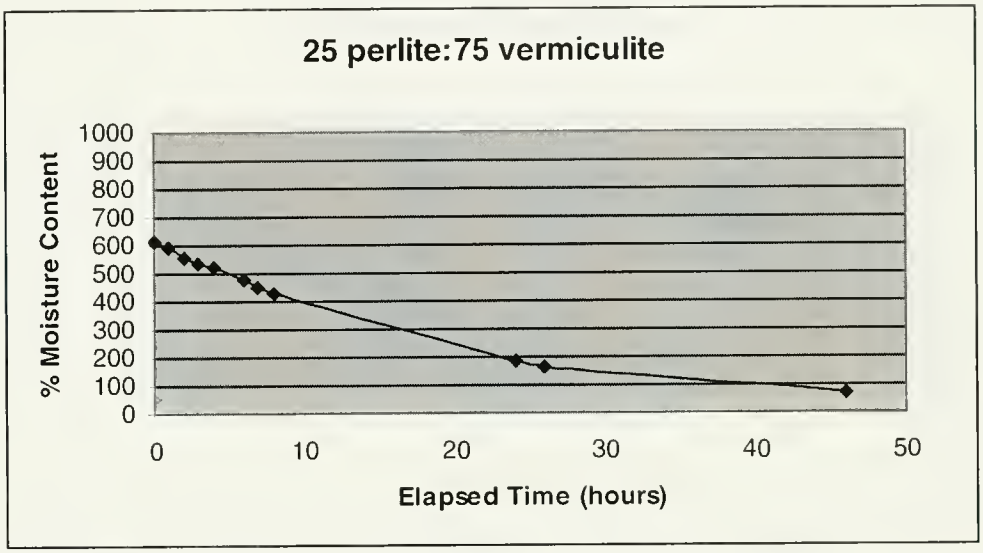

Figure 18. Evaporation curve of a 25 perlite: 75vermiculite mixture.

25 perlite:75 vermiculite--Initial Dry Mass 8.00g		
Time (hours)	**Sample Mass (grams)**	**% Moisture**
0	57.14	614.25
1	55.16	589.50
2	52.51	556.37
3	50.89	536.12
4	49.53	519.12
6	46.11	476.37
7	44.02	450.25
8	42.42	430.25
24	23.09	188.62
26	21.21	165.12
46	13.71	71.37

Table 13

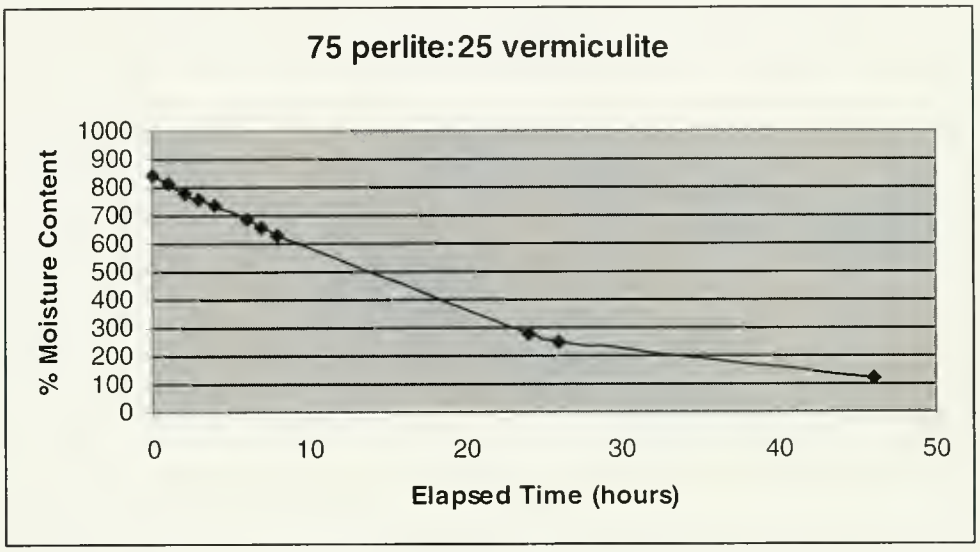

Figure 19. Evaporation curve of a 75 perlite: 25 vermiculite mixture.

75 perlite:25 vermiculite--Initial Mass 7.95g		
Time (hours)	**Sample Mass (grams)**	**% Moisture**
0	75.08	844.40
1	72.96	817.74
2	69.90	779.24
3	68.04	755.85
4	66.43	735.60
6	62.46	685.66
7	60.02	654.97
8	58.13	631.19
24	30.24	280.38
26	27.66	247.92
46	17.59	121.26

Table 14

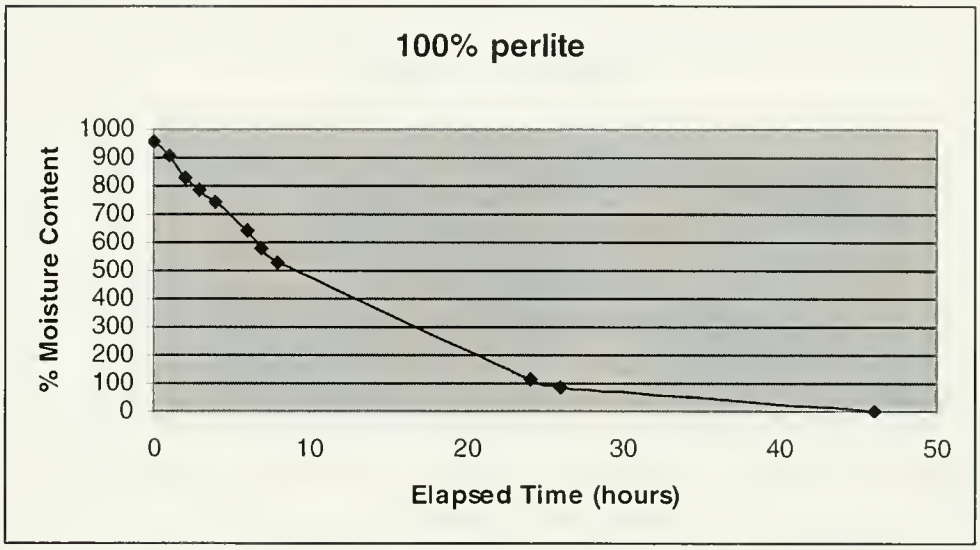

Figure 20. Evaporation curve of 100% perlite.

100% perlite--Initial Dry Mass 2.61g		
Time (hours)	Sample Mass (grams)	% Moisture
0	27.62	959.39
1	26.33	908.81
2	24.32	831.80
3	23.07	783.91
4	22.00	742.91
6	19.34	641.00
7	17.70	578.16
8	16.41	528.74
24	5.54	112.26
26	4.88	86.73
46	2.70	3.45

Table 15

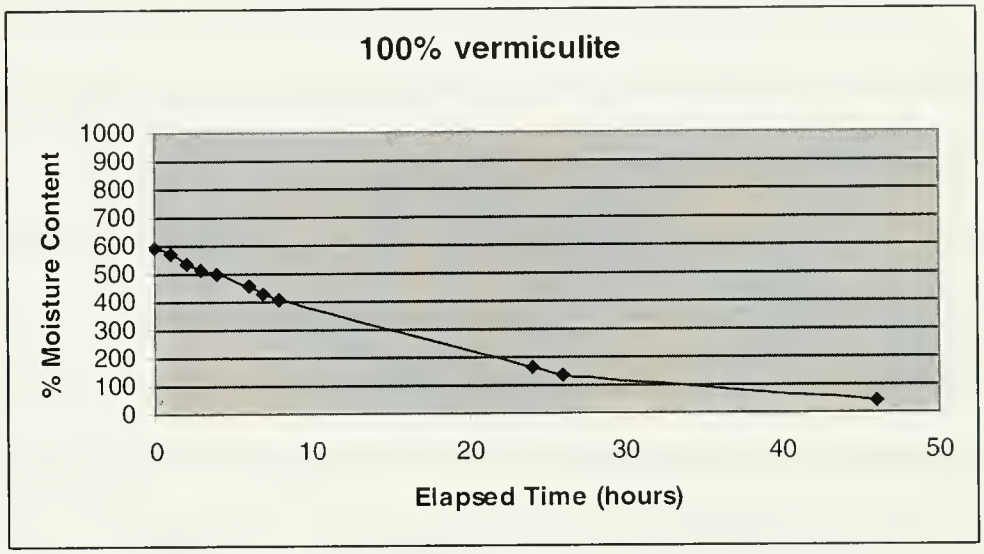

Figure 21. Evaporation curve of 100% vermiculite.

100% vermiculite--Initial Dry Mass 6.40g		
Time (hours)	**Sample Mass (grams)**	**% Moisture**
0	44.43	594.22
1	42.87	569.84
2	40.74	536.56
3	39.44	516.25
4	38.34	499.06
6	35.55	455.47
7	33.85	428.91
8	32.56	408.75
24	16.72	161.25
26	15.07	135.47
46	9.23	44.22

Table 16

4.4.4 Geotextile

Geotextiles are woven or non-woven sheet materials that were originally manufactured for civil engineering applications such as reinforcement, drainage, and erosion control in roadway construction. They are known as filter fabrics that hold silt and sediment while allowing water to pass. For use at Çatalhöyük, the monofilament, needle-punched geotextile was chosen for the testing program of the protective system. The non-woven material is highly permeable and sheds less water than the woven. A material that sheds too much water should be avoided as it may cause drainage problems resulting in run-off puddles. If water is absorbed, it is hoped that the perlite/vermiculite packing mixture will hold it and release it slowly through evaporation. The needle-punched geotextile is a spongy, soft-draping material made from black polypropylene fiber. It is able to stretch and conform to the shape of the adjacent surface. This feature is particularly important when considering wall irregularities and the possibility of plaster wall reliefs at Çatalhöyük. However, as geotextiles are subjective to UV-degradation, they should not be used for prolonged periods in direct sunlight

After the initial water absorption tests narrowed down the 75 perlite: 25 vermiculite mixture by volume as the optimal packing support material (see 4.4.3), it was enclosed in a geotextile "cushion" for further testing on a laboratory facsimile of the "assemblies". The walls of the system were made of water saturated sponges. One system was open, with the geotextile "cushion" attached to it. The other system was sealed, with the sponges and geotextile "cushion" enclosed, allowing no air circulation.

The geotextile "cushions" were weighed dry, before being applied to the saturated systems. The complete systems were weighed at regular time intervals in order to monitor moisture loss. After 91 hours, the systems were disassembled and the geotextile "cushion" was again weighed to determine how much moisture it gained. Again, at regular time intervals, for the next 192 hours, the geotextile "cushions" were weighed in order to record the rate at which they lost moisture. The results are below:

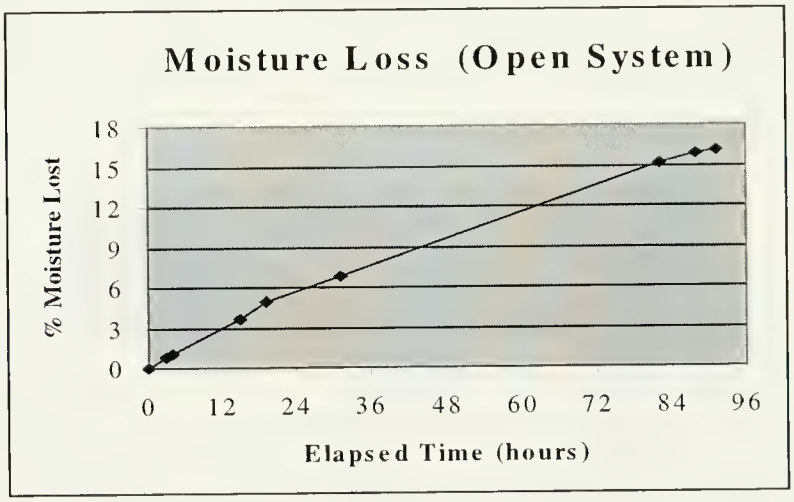

Figure 22

Moisture Loss in Open System		
Time (hours)	**Sample Mass (grams)**	**% Moisture Lost**
0	583.90	0
3	578.90	0.86
4	577.90	1.03
15	562.40	3.68
19	555.01	4.95
31	544.24	6.79
82	494.94	15.23
88	491.36	15.85
91	489.51	16.16

Table 17

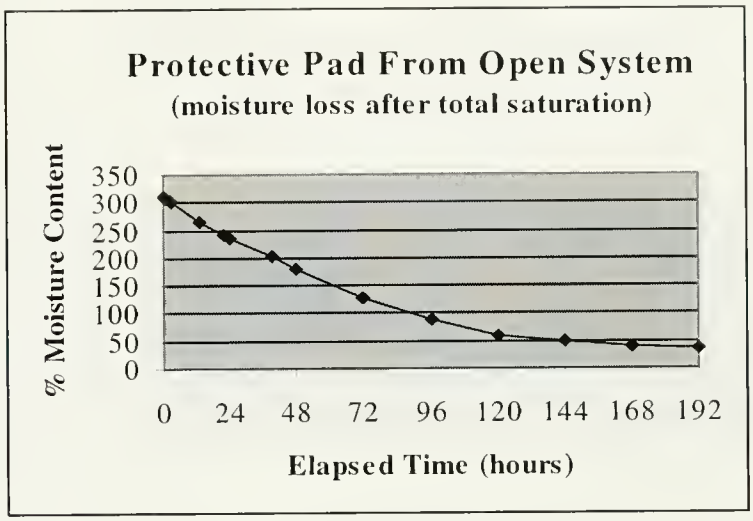

Figure 23

Protective Pad from Open System Initial Mass--54.82g Saturated --226.05g		
Time (hours)	Sample Mass (grams)	% Moisture
0	226.05	312.35
1	223.05	307.72
2	221.56	304.16
3	219.21	299.87
13	200.62	265.96
22	188.25	243.40
23	185.76	238.85
24	184.53	236.61
39	203.12	203.12
48	179.51	179.51
72	125.10	128.20
96	102.48	86.94
120	87.51	59.49
144	81.32	48.34
168	75.69	38.07
192	74.78	36.41

Table 18

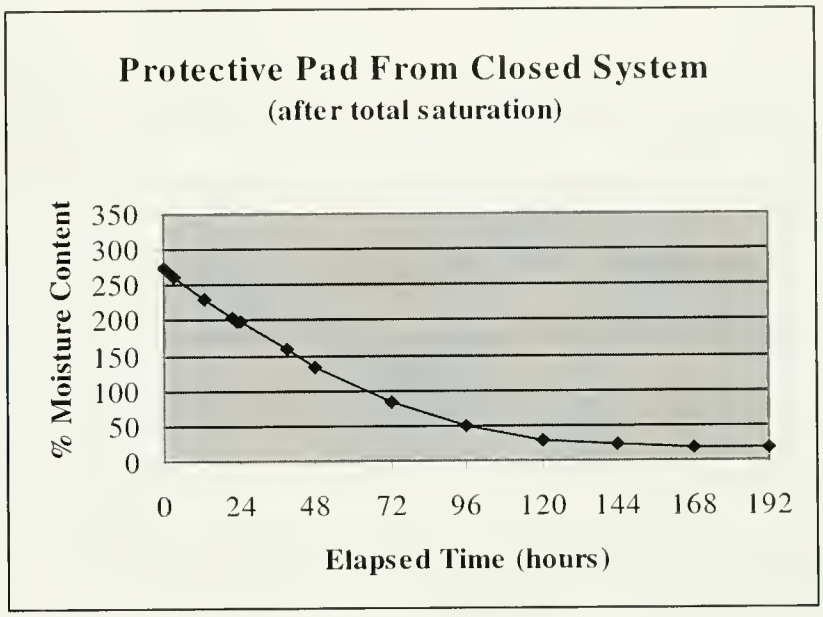

Figure 24

Protective Pad from Closed System Initial Mass--54.82g Saturated --226.05g		
Time (hours)	Sample Mass (grams)	% Moisture
0	151.23	273.87
1	149.31	269.12
2	147.89	265.61
3	146.25	261.56
13	132.93	228.63
22	123.28	204.08
23	121.26	199.78
24	120.24	197.26
39	105.14	159.92
48	94.54	133.72
72	73.82	82.50
96	60.43	49.39
120	52.08	28.75
144	49.75	22.99
168	48.07	18.84
192	47.96	18.57

Table 19

4.5 Monitoring

The moisture content, or rather the rate of drying, of the assembled walls, was monitored using a KS-D1 Digital Soil Moisture Tester and GB-1 Gypsum Soil Blocks by the Delmhorst Instrument Company (range 0.1 to 15 Bars Tension with a 0-100 arbitrary scale). A series of three gypsum sensors, cast around two electrodes, were buried in the bottom, middle, and top of both sides of the each wall. Thus, a total of six sensors were used for each model.

The moisture tester measures resistivity by measuring the current that flows between the electrodes and the electrical resistance of the gypsum blocks. The meter readings may be interpreted in "Soil Moisture Tension" or "Blocks Resistance". The meter allows one to record and plot the relative moisture content in the assemblies. The greater the moisture content, the higher the reading. To facilitate measurement readings and to avoid prematurely damaging the plastered surfaces with loose wires, the lead wires of the sensors fed out of small holes drilled in the back of the assembly. The plugs were placed at the plaster interface in the headjoint, assuming that the interface would be the critical contact point for the transfer of moisture in the mudbrick walls to the plastered surface.

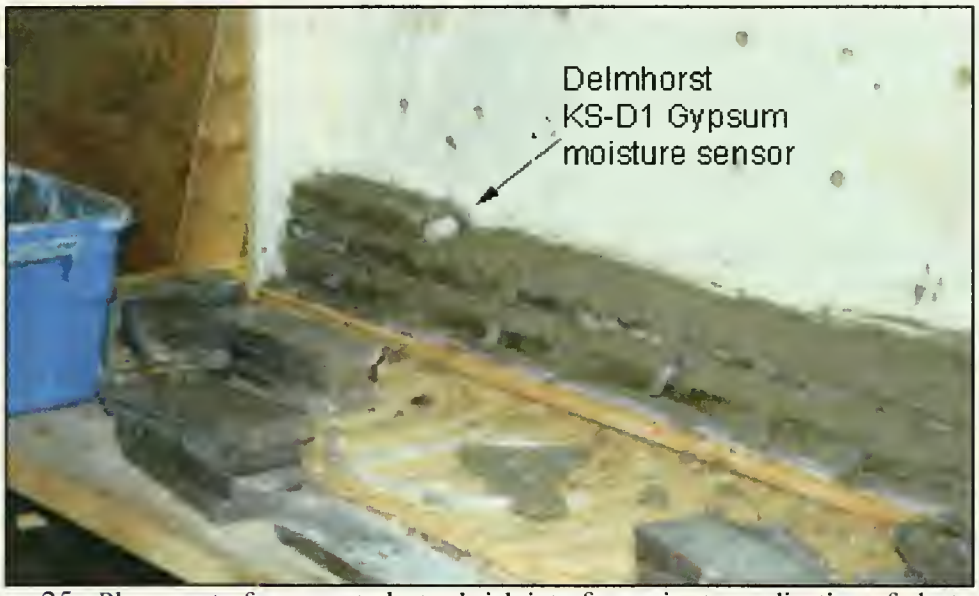

Figure 25. Placement of sensor at plaster-brick interface prior to application of plaster.

4.6 Testing Procedure

Once the models were assembled, the fronts were kept covered with plastic film to prevent surface evaporation before the testing began. Water was fed into regularly spaced channels from the rear of the wall assemblies in order to raise the overall moisture content of the walls. Because the testing program monitored and plotted moisture loss, it was necessary to ensure a high moisture content at the outset. Water was fed into the walls until it was deemed that they could not safely receive any more without jeopardizing the integrity of the applied surface finishes. This was determined visually. Water was no longer injected into the wall only when it began seeping through the surface finishes, suggesting sufficient saturation.

Once the walls reached a sufficient state of saturation, the testing program was ready to begin. To facilitate adequate monitoring, one model was tested at a time. Knowing that the test would be destructive in nature, the researcher was wary about encountering unforeseen problems while simultaneously testing both walls. Should any such problems occur, details would be addressed before implementing the testing program on the second wall.

4.6.1 Model I—One Cycle of Continuous Heat

The first model was vertically divided in half with a strip of wood that fit flush against the plaster surface. The left half was left exposed and unprotected. A two and a half inch deep wooden frame, to which was stapled a geotextile "sack", was built around the right half of the model. The front of the protective geotextile "sack" was even with the outer edge of the wooden frame, while the back of it conformed to the contours of the plastered surface of the wall. Once the geotextile was in place, a 75 perlite: 25 vermiculite volumetric mixture was poured into an opening at the top of the geotextile "sack". Care was taken to fill all voids, making contact at the plaster surface. When the "sack" was filled to capacity, measuring between two and a half to three inches thick, it was stapled shut.

In order to accelerate the rate of drying, a series of four 250-watt infrared heat lamps were aimed at the entire model. Two lamps were focused on each side of the model, each one placed two feet from the surface. Thus, the entire surface was simultaneously subjected to the same heat intensity. The heat lamps, projecting a

temperature of 34° C, were left on continuously for six hours. Another seventeen hours, at 22° C, elapsed before the protective system was removed.

4.6.1.1 Observations

Within the first five minutes, the unprotected surface began developing small stress or map cracks. For the first half an hour, the moisture readings of the unprotected side gradually increased. This was probably due to the moisture being sucked from the brick walls and passing through to the surface and sensors.

The first visible failure occurred twenty minutes after beginning the test. A small section of the top plaster layer flaked and fell off the wall. The first drop in moisture of the unprotected side occurred thirty-five minutes into the test. Moisture readings initially dropped in the middle of the wall. This may have been due to a slight elevation in temperature where the two heat lamps overlapped.

By forty-five minutes, the unprotected side began developing noticeably more cracks. After one and a half hours, the underlying painted layer became more exposed as the surface layer continued to flake and fall from the wall. After two hours, the top of the wall began to consistently lose moisture, while the base of the wall continued at a stable reading for five and a half hours. After this point, the entire surface of the unprotected side lost moisture more rapidly. Throughout this time, the protected side had stable moisture readings.

The heat lamps were turned off after six hours. It is unlikely that the site would experience solar radiation for longer than this. Once the lamps were turned off, the

protected side also began losing moisture, although at a slower rate than the unprotected side.

The protective system was removed 23 hours after the testing began. The unprotected side suffered fairly extensive loss of the surface plaster and deep cracks that went through to the mudbrick substrate. Overall, there was little total loss of the plastered surface. The results of the testing seemed to indicate that most of the damage occurred between plaster layers. The protected side was still damp to touch when the protective system was removed. The color was greyer than the dry, white unprotected surface.

After 32 hours, the surface of the unprotected side continued to flake and fall from the wall. After 57 hours (34 hours after the protective system was removed), the protected side began showing stress or map cracks. Small areas of the top plaster layer flaked off the wall, revealing some of the painted surface below.

A 1.5cm core sample was taken after 81 hours, from the base of the unprotected side of the wall. The core included two layers of the plaster finish coat, the base coat, and the mudbrick surface. According to the 6.6 reading from the Delmhorst KS-D1 Soil Moisture Tester, this was the driest part of the wall. The material was weighed, oven-dried for 24 hours, and again weighed to determine the moisture content. The moisture content was calculated at 15%. Unfortunately, a core was not taken at the outset of the test. Such a reading would have been a useful comparative tool. However, simply based on visual assessment, the protective system obviously helped mitigate damage caused by dessication of the wall surfaces.

The results of the moisture meter readings are given below:

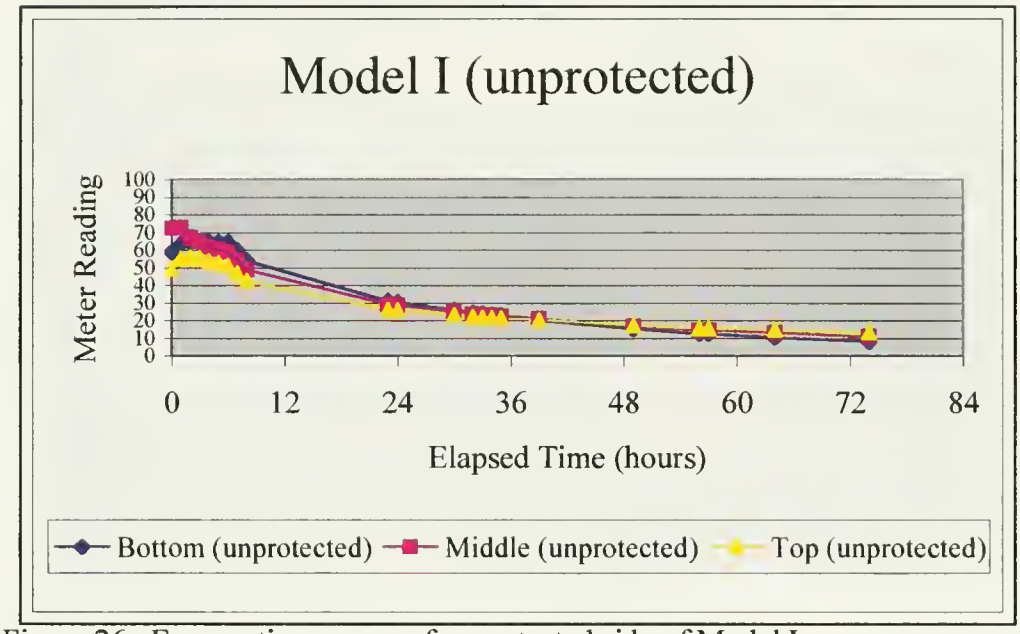

Figure 26. Evaporation curves of unprotected side of Model I.

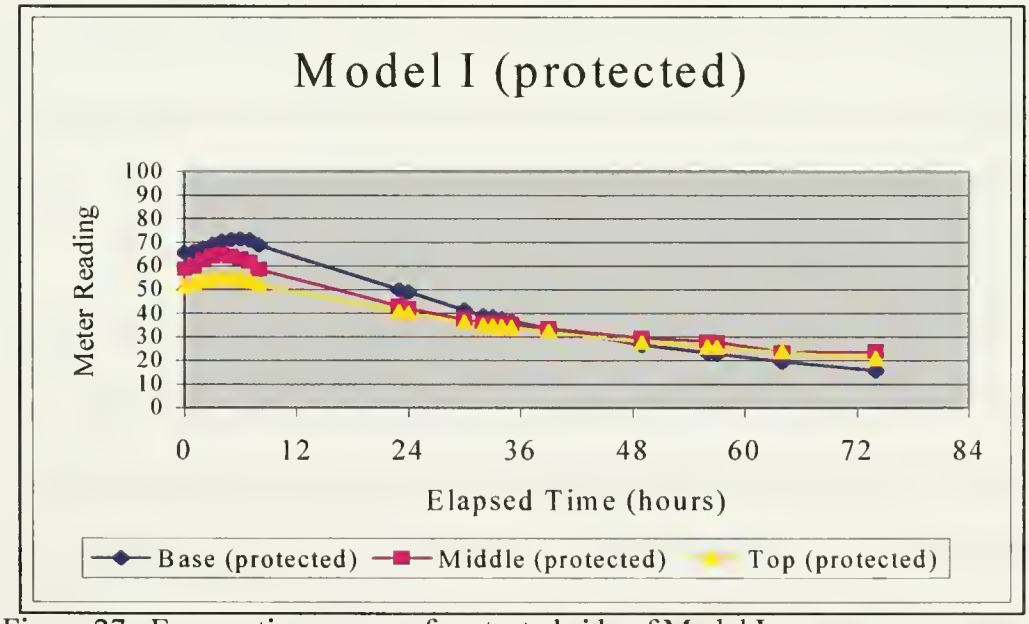

Figure 27. Evaporation curves of protected side of Model I.

4.6.2 Model II—Continuous Cycling

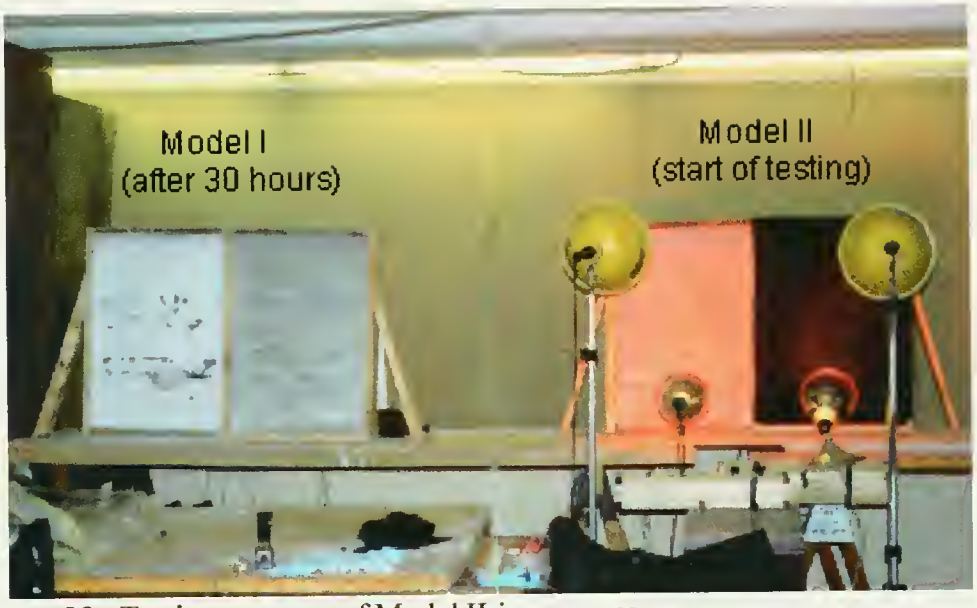

Figure 28. Testing program of Model II in progress.

The initial set-up of the second model was the same as for Model I. However, whereas Model I tested the effects of continuous heat on the wall assembly, Model II tested the effects of temperature cycling. As with Model I, two 250-watt infrared heat lamps were focused on each side of the assembly, each placed two feet from the surface.

The testing followed a continuous five-hour cycle in which the lamps were initially left on for one hour, and turned off for one hour. After five hours, the lamps were left off for twelve hours, and then turned on for another seven hours. They were then off for another fourteen hours. A final cycle of heat was used for four hours until the protective system was removed after a total time of 48 hours. As with Model I, moister meter readings were recorded at regular intervals for both sides of the wall.

4.6.2.1 Observations

After one hour of exposure to the heat lamps, the surface reached 30° C. As with Model I, small stress cracks quickly formed. After an hour, the lamps were turned off and the temperature dropped to 21° C. After two and a half hours, extensive through-cracking was apparent on the upper section of the unprotected wall section. During the first five hours, the unprotected side gradually began losing moisture, while the protected side remained virtually unchanged.

After nine hours, the protected side of the wall indicated its first slight loss of moisture, whereas the unprotected side continued to lose moisture at a quicker rate. The unprotected side began exhibiting through-cracking throughout the wall surface. After 26 hours, the cracks were noticeably jeopardizing the integrity of the plastered surface. Whereas the damage in Model I was mostly interlayer, here the damage clearly extends to the mudbrick substrate.

After 48 hours, the protective cover was removed. As with Model I, the protected side of Model II was virtually unchanged. The wall was still damp to touch and slightly greyer in color than the unprotected side. There were a few hairline stress cracks and one area of less than a cm^2, which lost the top layer of plaster.

Even after the protective system was removed, the side that had been left unprotected continued to lose moisture at a more rapid rate. This may be attributed to the increased surface area produced as a result of the deep cracks. Moisture was only evaporating on a flat surface on the protected side, whereas it was evaporating on the wall

surface as well as within the cracks on the unprotected side. Thus, once cracks form, damage through dessication is accelerated, and mechanical adhesion is compromised.

Three hours later, core samples were taken at the base, middle and top of both the unprotected and protected sides of the wall to compare moisture contents. The results are given below:

Assembly II—Final Moisture Content	
Unprotected Side	**Protected Side**
Base—9.81%	Base—31.05%
Middle—10.13%	Middle—29.53%
Top—11.72%	Top—39.53%

Table 20

A sample of the plaster was also taken to test for soluble salts, being careful not to remove any of the mortar or mudbrick substrate. Not surprisingly, the plaster tested positive for sulfates, indicating that the sodium sulfate solution that was added to the mudbricks had migrated to the surface and was recrystallizing upon moisture evaporation.

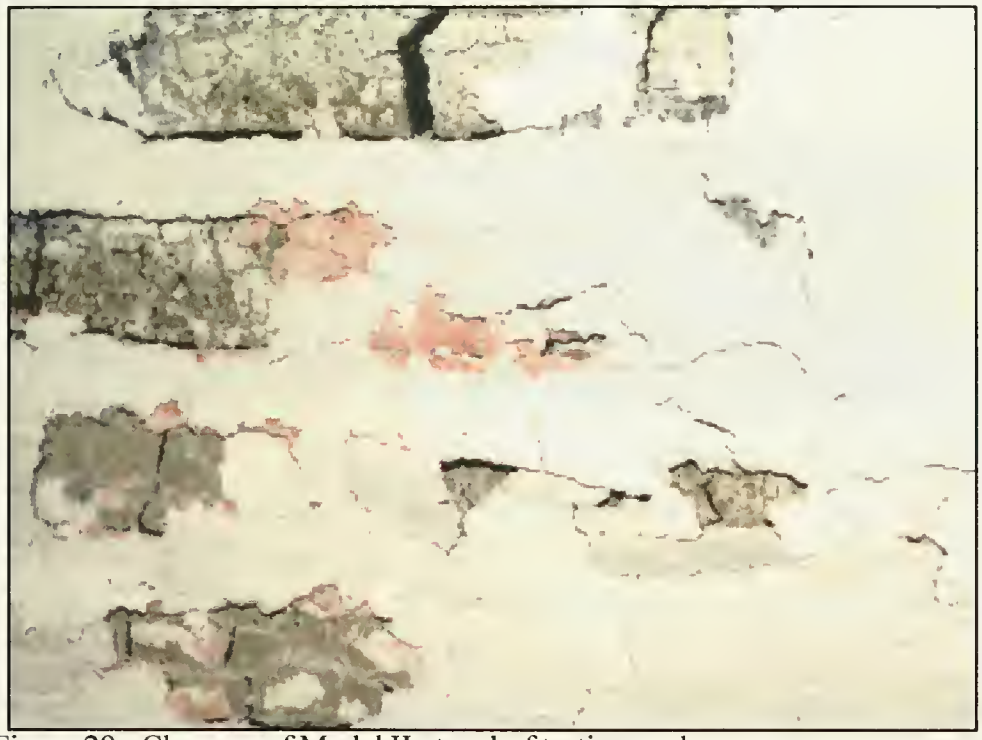

Figure 29. Close-up of Model II at end of testing cycle.

The results of the moisture readings are given as follows:

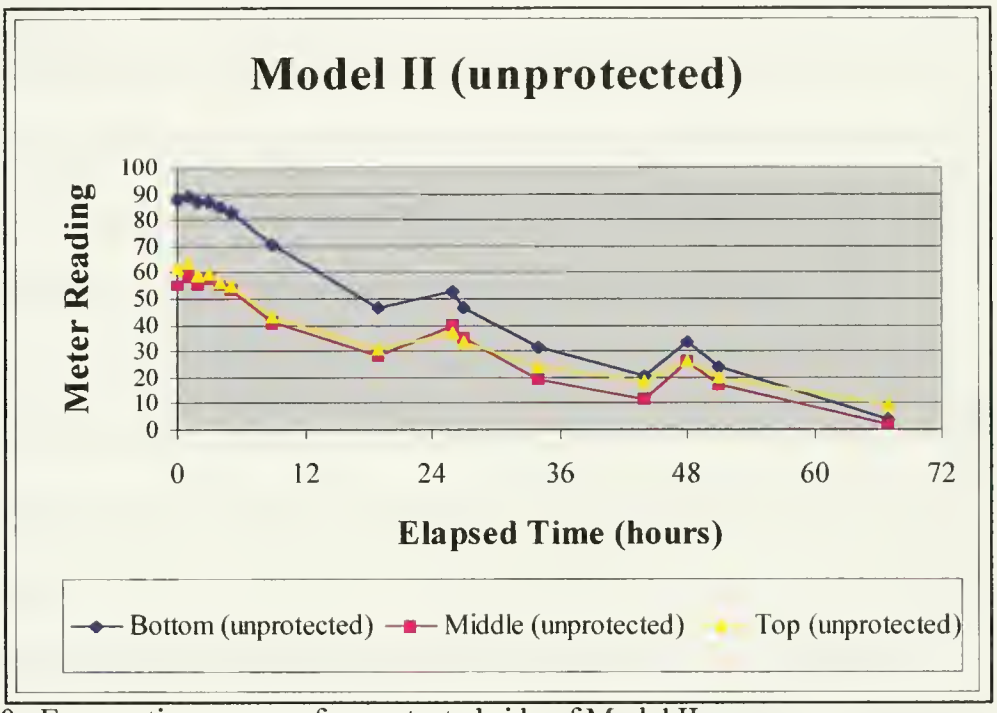

Figure 30. Evaporation curves of unprotected side of Model II.

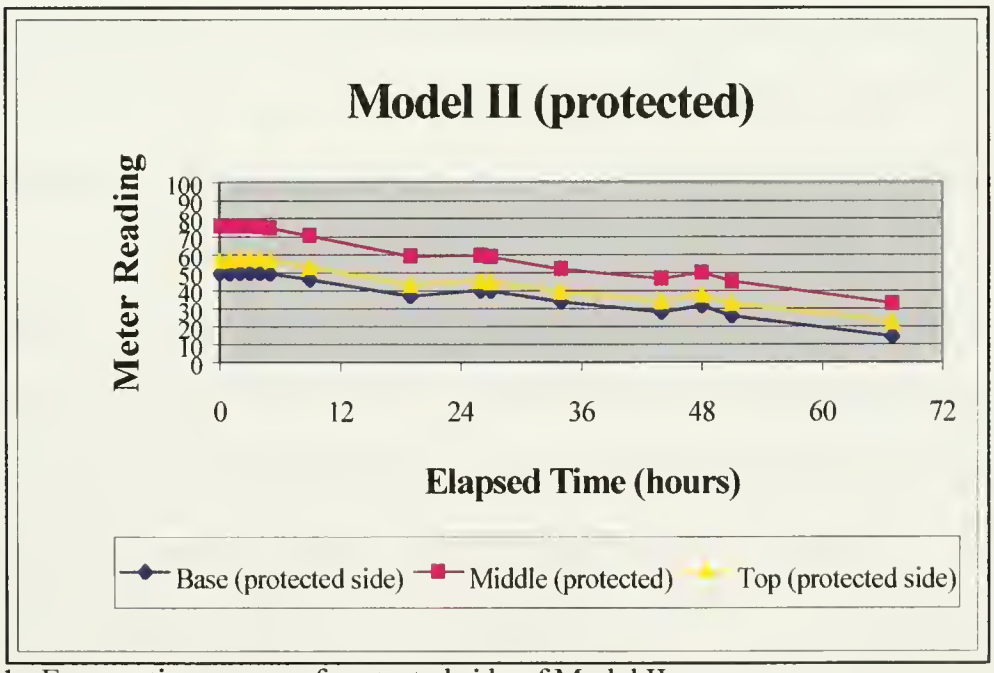

Figure 31. Evaporation curves of protected side of Model II.

5.0 Conclusion:

By destabilizing the burial environment through the removal of protective earth covering, the archaeological process is, by its very nature, destructive. The role of the archaeological conservator is to minimize damage that is inherent in the archaeological process without jeopardizing the investigative goals of the archaeologist. The archaeological conservator must find a delicate balance to provide maximum site and artifact protection while ensuring access of material remains for study and interpretation.

Any conservation intervention requires an understanding of the physical and chemical properties of a given material. At Çatalhöyük, it is the inherent properties of the earthen materials that make them particularly vulnerable to damage relating to dessication of the exposed structures. As witnessed on site, rapid drying of the plastered surfaces and relief sculptures begins to occur immediately upon exposure. The walls experience a migration and recrystallization of soluble salts to the surface, shrinkage cracks, flaking, and finally detachment of discreet layers or entire plaster systems. Plaster detachment is further accelerated in areas with root intrusions, animal burrows, and structural deformation and displacement.

The painted plaster walls and relief sculptures are fundamental in the overall understanding and interpretation of the site. Because of the unique information they offer to our understanding of early human settlement, every effort must be made to ensure their preservation. This can be accomplished only through the implementation of a comprehensive conservation program at all stages of the excavation. Such a program can only be effectively implemented if an open dialogue exists between all members of the

excavation, particularly between excavators and conservators. While the immediate aims of these two parties often seem to be at odds, all members do share a common goal. An effective excavation program should provide adequate means to maximize both the recording of information and material preservation.

As already mentioned in Chapter One, the long-term conservation interventions will be partially dependent on the archaeological and interpretive values of specific excavated areas. These may include documentation, removal of wall paintings without the mudbrick substrate, removal of entire wall sections, consolidation *in situ*, or backfill. Regardless of the eventual decision, it is hoped that this thesis has illustrated that short-term preventative measures not only can, but must, be taken to facilitate the final decision process. Immediate, non-obtrusive intervention as a form of preventative conservation should be implemented as the first step in a comprehensive conservation program. Based on site investigation, materials analyses, and the creation of simulated models to examine the effects that moisture and salts have on earthen walls, this thesis has tried to illustrate the urgency in incorporating preventative measures into the excavation process. The damage caused by rapid dessication is very real, and often irreparable. However, while deterioration is a natural, unavoidable process, it can be mitigated and monitored.

5.1 Recommendations for Further Study

While this thesis focused on one aspect of preventative conservation, it must be stressed that the conclusions are far from exhaustive. The materials for the laboratory testing program were chosen based on the results of a literature survey, their accessibility and low cost. While the protective system outlined in this thesis did provide positive results, the investigator does not mean to imply that other materials will not work.

Most importantly, one must remember that the results presented are intended for application as the first step in a multi-phased comprehensive conservation program. While the protective system does effectively address the mitigation of damage caused by dessication, it does not address such destabilizing factors as root intrusion and animal activity.

The total conservation program at Çatalhöyük may need to address the construction of a permanent shelter with adequate drainage. Structural stabilization, grouting and reattachment of plaster layers need to be addressed. While initial research for using consolidants to treat wall sections has begun, this needs to be continued before large-scale chemical treatment can effectively be implemented on site. Because wall sections may need to be removed to off-site locations to allow the excavation to reach lower occupation levels, a safe, effective means of wall removal, transport and storage needs to be addressed. Finally, further research is needed to assess the long-term ramifications of backfilling areas of the site

Appendix A:
RESOLUTIONS AND RECOMMENDATIONS FROM THE INTERNATIONAL SYMPOSIA ON THE CONSERVATION OF MUDBRICK

The following is from the 2nd *International Symposium on the Conservation of Monuments in Mud Brick,* Yazd, 6-11 March 1976.

Resolutions:

1) Archaeological Sites

That no archaeological excavations of sites likely to contain the remains of structures in mud brick should be undertaken unless a provisional conservation policy has been established and has been included in the excavation budget agreed upon by archaeologists and the competent authorities. Such a provisional conservation policy should anticipate differing levels of intervention depending upon the importance of the finds. For example:

a) Sites whose documentation or public importance does not justify the expense of conservation should be backfilled with sand or sieved soil after a complete record has been made…
b) Light shelters should be built as a temporary measure to protect the more important mud brick structures, or as preliminary to further work when the find forms part of a larger structure to be investigated.
c) Restoration work should be undertaken for major sites including as necessary, physical stabilization of the structure, installation of systems of waterproof capping and drainage…

All action for the conservation of archaeological sites containing mud brick structures should be undertaken at the earliest opportunity and before decay has set in. Only when sites are adequately guarded can the efficacy of conservation programs be guaranteed.

The following is from the 3rd *International Symposium on the Conservation of Monuments in Mud Brick*, Ankara, 1980:

Recommendations Approved in Ankara (4TH October, 1980)

2. Archaeological Sites

2.1 Immediate Protection During and After Excavation:
Newly excavated mud-brick material must be given immediate temporary protection until such time as its importance is defined and a definite conservation plan is established. Such temporary protection should rely primarily upon the materials and techniques available locally. The ideal temporary protection should satisfy the following requirements:

-it should provide adequate protection against direct erosion by rain or melting snow.
-it should afford sufficient thermal insulation to avoid condensation or the "greenhouse effect" and, preferably, be permeable to water vapor.

-it should be easy to remove and to put back in place when study and/or inspection is necessary.
-it should have a minimum useful life of five years, with periodic maintenance, if required.
-the protection plan should include provisions to drain rain water and avoid erosion at the base of the walls.

Such temporary protection measures might include:
-straw mats covered with mud plaster.
-capping (coping) projecting sufficiently beyond the top edges of walls so as to avoid the flow of rainwater over the vertical surface. A layer of reeds, or other vegetable matter, covered with soil, could be used for this purpose.

The cost of protective treatment should be included in the budget of any archaeological campaign, and sufficient time should be allotted in the program of each excavation for such work.

An excavated mud-brick structure should never be left exposed to the environment from one archaeological campaign to another.

Application of temporary protection as soon as possible is meant to provide the director of the excavation with sufficient time to:

a. complete the archaeological study of the structure
a. complete the study of material and environmental conditions;
b. reach a decision on the future treatment of the structure (back-fill or conservation for exhibition).

3. Construction of Shelters

It is recommended:

3.1 That the design study of modular systems for the construction of low-cost protective shelters (either full or partial enclosure) be undertaken.

3.2 That shelter design concepts be developed by professionals from different disciplines (i.e. architecture, archaeology, conservation) and tested jointly in the field, with particular attention to materials that are locally available.

4. Research on Conservation Treatments

It is recommended:

4.1 That methods of testing be standardized;

4.2 That comparable surfaces be used to test the relative merits of the various systems proposed, both in the lab and in the field;

4.3 That pilot field projects be used to test conservation systems on entire structures.

APPENDIX B:
IN SITU ENVIRONMENTAL PROTECTION OF ARCHAEOLOGICAL SITES (LITERATURE SURVEY)

Agnew, Neville (GCI) "Adobe Preservation—Fort Seldon Adobe Test Wall Project" *Research Abstracts of the Scientific Program, December 1994*, 142-147.

Project Site(s): Fort Seldon

Principle Research Concern: Develop techniques to preserve archaeological and historic adobe/mudbrick structures from weathering.

Materials/Methods: Consolidants
Physical protection: aerotextiles, geotextiles, composite fiber geobars as structural reinforcing elements.

Comments: Untreated walls quickly disintegrated.

Chiari, Giacomo. "Treatment of Adobe Friezes in Peru" *Third International Symposium On Mudbrick (Adobe) Preservation*, 29 September-4 October, 1980, Ankara, ICOM, ICOMOS, 39-45.

Project Site(s): Huaca Garagay, Chavin (1300 BCE),
Casa Velarde, Chan Chan, Chimu (1100-1450 CE)

Principle Research Concern: Protect exposed mudbrick friezes, address friability.

Materials/Methods: Build roof, protect from direct sunlight, cover surface with sacrificial soil to combat salt formation on surface, chemical consolidants.

Comments: Mixed technique works best. No technique works in isolation.

Cobau, Andreina Costanzi. "Excavated Wall Plasters: Conservation Problems", *Preventive Measures During Excavation and Site Protection. Conference. Ghent, 6-8 November, 1985.* ICCROM, Rome, 1986, 103-110.

Project Site(s): Crypta Balbi, Rome. Medieval frescoed wall.

Principle Research Concern: In situ conservation assistance to combat rising damp, water infiltration from the rear, biological attack and migration of soluble salts to the surface. Upon excavation, the plasters lose cohesive properties.

Methods/Materials: Temporary plastic roof and gutter built two meters above wall in order to allow air circulation and prevent condensation or "greenhouse effect". While excavating, leave 155mm of soil in front of the frescoed wall. The soil, serving as a sacrificial layer to slowly evaporate water and to isolate the soluble salts, assists the gradual transition from the constant humidity of the ground to the variations of the open air.

Comment: In situ intervention is a necessary first step in overall interpretation and conservation program.

Dowdy, Katherine and Michael Romero Taylor. "Investigation into the Benefits of Site Burial in the Preservation of Prehistoric Plasters in Archaeological Ruins." *7th International Conference on the Study and Conservation of Earthen Architecture: Silvas, Portugal, 24-29 October, 1993.* pp. 480-487. ICOMOS: Lisbon, 1993.

Site(s): Chaco Culture National Park, N.M. (850-1120 CE), excavated 1890s.

Principle Research Concern: Assess impact of backfilling.

Methods/Materials: Using historic documentation, compare current conditions of five rooms after 70-90 years of burial to conditions at time of early excavation and just prior to backfilling. Pits were excavated leaving 30cm of fill in contact with the plaster to let them dry slowly. To further slow down the rate of drying, temporary shelters were built to shield plaster from sun and wind.

Comments: The effects of drying out were most pronounced in the initial four hours of exposure, after which an equilibrium with ambient conditions was seemingly established. The plaster surfaces that were misted to slow down the rate of drying out suffered from cycles of wetting and drying. Overall, the preliminary results proof positive. Depth of fill is an important factor to consider.

Espinosa, Ahustin. "Conservation and Restoration of the Murals of the Temple of the Paintings in Bonamak, Chiapas". *In Situ Archaeological Conservation. 6-13 April, 1986, Mexico.* pp. 84-89. LA: INAH/GCI, 1987.

Site(s): Bonampak, Chiapas, Mexico

Principle Research Concern: Slowly dry recently exposed walls in order to conserve the paintings. Address issues of capillary humidity, microflora, and expansion and contraction due to temperature variations on site.

Methods/Materials: Build drain to aid in the evaporation of moisture, construct walls around the monument to control the air circulation.

Comments: Deforestation of the area and monument seriously altered the moisture conditions in the chambers. The environmental alteration accelerated the rate of evaporation, causing salts to crystallize on the surface.

Gamarra, Ricardo Morales. "Conservation of Structures and Adobe Decorative Elements in Chan Chan" *International Symposium and Training Workshop on the Conservation of Adobe: Final Report and Major Papers, Lima-Cusco Peru.* 10-22 September, 1983. ICCROM: Rome, 83-89.

Project Site(s): Chan Chan, Peru

Principle Research Concern: Mitigate intrinsic and extrinsic material alteration.

Materials/Methods: Protect original adobe bricks with rows of new ones. Cap the wall tops with a mixture of soil and chemical consolidants.

Comments: Ethyl silicates, although irreversible, seem to be best option for waterproofing. To protect against water, drainage needs to be addressed.

Goodburn-Brown, Dana and Richard Hughes. "A Review of Some Conservation Procedures for the Reburial of Archaeological Sites in London." *Archaeological Conservation and its Consequences. Preprints of the Contributions to the Copenhagen Congress, 26-30 August, 1996*, pp. 65-69, Ed. A. Roy and P. Smith, London:IIC, 1996.

Site(s): Suffolk House, London: Opus Signinum floor section and wall plaster. Guildhall Yard, London: Timber and masonry Roman Amphitheater, found 1988.

Principle Research Concern: Stabilize and protect archaeological features before backfilling the test pits. Conform to conservation ethics in regard to minimum intervention, reversibility, and lack of chemical interaction.

Methods/Materials: Line excavated areas with layer of geotextile (Terram), washed sand, and site soil.

Comments: At Suffolk House, backfilling was carried out either in tandem with archaeological investigation, or immediately following. What role does the level of soil aeration play in the process? Guildhall Yard was uncovered five years later. The area had been driven over by machinery. Many timber surfaces suffered damage due to both compression and biological attack. Before reburial, t the treatment of wood surfaces to prevent biological attack should be investigated.

Lewis, Hillary. "Experiments in Mudbrick Conservation at Tepe Nush-I Jan" *Third International Symposium On Mudbrick (Adobe) Preservation*, 29 September-4 October, 1980, Ankara, ICOM, ICOMOS.

Project Site(s): Tepe Nush-I Jan, Iran (excavation begun in 1967)

Principle Research Concern: Identify decay mechanisms, and implement preservation system to mitigate effects of rising damp, salt efflourescence, wind-driven rain, dehydration.

Methods/Materials: Reburial, application of thick coats of protective mud plaster (kaghel), capping with reed mats, kaghel, guni (sacking soaked in tar), perforated polythene to prevent condensation. Installation of steel roofs on freestanding columns in 1974.

Comments: Good start, but not enough. Cracking of the walls is due to the General drying of surfaces upon excavation. The roof does not prevent wind currents from accelerating dehydration cracks. Rising damp, wind-driven rain, and pigeons are not dealt with.

Nardi, R. "Conservation of the Excavation: The Crypt of Balbus in Rome", *Preventive Measures During Excavation and Site Protection. Conference. Ghent, 6-8 November, 1985.* ICCROM, Rome, 1986, 91-98.

Project Site(s): Crypta Balbi, Rome. 2500 sq. meters. First period of construction dates from 13 BCE. Excavation was begun in 1981.

Principle Research Concern: Permit the excavation process to proceed without slowing down the rate of drying out of the 4 meter high mudbrick wall.

Materials/Methods: Rigid roof of metal tubing and corrugated plastic, flanked by bamboo screening to limit isolation, overheating and drying of the walls. "Drop by Drop" wetting system to prevent shrinkage cracks, biocide treatment.

Comments: The immediate measures were successful preparations for further consolidation and stabilization. Excavation continued unimpeded

Sedlak, V. "Report on the Evaluation Study of the Hexashelter Modular Shelter System". Final Report to the Getty Conservation Institute, June 1989.

Project Site(s): Orpheus Mosaic, Kato Paphos, Cyprus

Principle Research Concern: Evaluate structural stability and footings of shelter.

Materials/Methods: same as Agnew entry, "The Hexashelter"

Vouve, Jean, Jacques Brunet, Pierre Vidal and Jacques Marsal. "Les Oeuvres Rupestres de Lascaux (Montignac, France): Maintien des Condtions de Conservation". *Studies in Conservation*, 28, 3 (1983), 107-116.

Site(s): Lascaux, France. Paleolithic cave paintings discovered in 1940.

Principle Research Concern: Conserve the paintings in situ in a cave with fluctuating conditions and seasonal variations. Find the ideal climate and conditions from the time of discovery (before overgrowth removal and arrival of tourists). Limit condensation.

Materials/Methods: Installation of mechanical system to regulate temperature and Humidity. Heat exchangers, a weak concentration of carbon dioxide, elimination of seepage water.

Comments: Caves are complicated environments. The area is subjected to External influences transmitted through the rock, water and air. Mechanical Installations need to be maintained to control the thermal conditions of the cave.

Weaver, Martin E. "The Use of an Inflatable 'Air-Dome" to Produce Controlled Conditions for an Archaeological Site". *Studies in Conservation*, 18, 2 (1973), 88-93.

Site(s): Can Hasan, Turkey. Neolithic period. Four four square meter trenches

Principle Research Concern: Produce controlled conditions during excavation, particularly for "difficult sites". Control or alter the microclimate under the dome. Compare the air velocities outside and within the dome.

Materials/Methods: Nylon cloth coated with polyvinyl chloride, air-lock door, two fans to pump in air, two generators, ballast to anchor the dome.

Comments: Constant humidity can only be obtained by installing automatically controlled air humidifiers. The generators often gave out, resulting in the deflation of the air dome within five to ten minutes. A lighter frame, such as an aluminum alloy, would be a better choice. Despite the imperfections, the dome did cut down the UV intensities, and reduced the air velocities. Moisture readings, humidity and temperature were higher within the 'air-dome' than outside.

Wilson-Yang, K.M., and George Burns. "Stability of the Tomb of Nefertari: 1904-1987", *Studies in Conservation.* 34 (1989), 153-170.

Site(s): Tomb of Nefertari, ca. 1240 BCE (No. 66, Valley of the Queens, Egypt)

Principle Research Concern: Five interacting factors contribute to deterioration: entry of flood waters and capillary absorption, salt formation, dehydration, air humidity and its fluctuations. The project focuses on a four-stage, long-term conservation scheme involving climatic and physical isolation of the paintings. Assessment of macroscopic changes within the tomb since its discovery in 1904. Plaster has lost both cohesion and adhesion.

Materials/Methods: In order to address the flood and climate control, the author suggests: constructing a temporary, non-invasive protection from flooding, implementation of climate control system (such as at Lascaux), construction of a permanent protective superstructure.

Comments: The lower chambers have undergone the most damage. The flood water and its effects may be responsible.

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