FORT SELDEN

ADOBE TEST WALL PROJECT

PHASE I

FINAL REPORT

FORT SELDEN STATE MONUMENT
RADIUM SPRINGS, NEW MEXICO

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BY

ANNE OLIVER
HISTORIC PRESERVATION AND ARCHITECTURAL CONSERVATION
SOCORRO, NEW MEXICO

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Executive Summary

Fort Selden was one of several small adobe forts established by the United States Army to protect settlers, travelers, and traders in the southern part of the Territory of New Mexico. The fort was constructed in 1865 and abandoned in 1891. Today, all that remains above grade are the remnants of the adobe walls and the stone walls of the prison. Below grade, the stone and adobe foundations of the walls are intact.

In response to the ongoing deterioration of the adobe walls at Ft. Selden and at other sites both historic and modern in the southwestern United States, the Adobe Test Wall Project was conceived. In 1985, a total of 15 walls were constructed for the Adobe Test Wall Project – Phase I in order to test a wide range of protective coatings, wall caps, and wall foundation treatments. Selection of the preservation techniques and materials for testing was made after a literature review and consultations with professionals in the adobe construction and preservation fields. The test walls were regularly monitored and photographed through 1991 in order to document their performance over time.

The purpose of this report was to critically analyze and assess the results of the Fort Selden Adobe Test Wall Project – Phase I, and included the following tasks:

- Review the design of the test wall project and the literature related to the methods and materials tested.
- Review the photographic, videographic, and written documentation of each test wall panel which was recorded on a monthly basis for approximately five years.
- Assess the current condition of each treatment applied to the test walls and assess why each treatment performed as it did.
- Conduct final photographic documentation of each treatment using the same datum points established in 1985.
- Review, analyze, and document treatments that were applied to the historic walls in the 1990s based on positive results from the 1985 test walls.
- Prepare a final report, including a synopsis of the above material, an evaluation of what was learned from the test walls, and recommendations for how the positive results might be tested for application at other earthen sites (including recommendations for further research).

Test walls 1 and 2 were used to test thirteen different protective coatings; treatments ranged from unamended earthen renders to amended earthen renders to spray-on and roll-on applications, and incorporated both traditional materials and modern chemicals. After fifteen years of exposure, the data provided definitive answers about the color matching and stability, erosion resistance, material compatibility, texture, and weathering patterns of the thirteen protective coatings. El Rey Superior Additive 200 displayed the best

overall performance. If amended earthen renders are selected for use on the historic walls at Fort Selden, a 10% El Rey 200 solution can be recommended as an additive for larger-scale trial testing in order to further evaluate its effectiveness at protecting the historic adobe walls and reducing the frequency of maintenance at Fort Selden. Other recommendations include further research into adapted chemicals and proprietary products, but especially the controlled research and application of traditional additives. As well, preparation and application parameters deserve further study, as does the use of combinations of materials to address different conditions at different areas in a wall.

Test wall 3 was designed to illustrate the erosional effects of four caps commonly used in New Mexico. The caps were composed of asphalt amended adobe bricks, cement-based render, and brick coping. All of the caps protected the top of the unamended adobe wall but may have accelerated the erosion of the unamended adobe immediately beneath the cap. Unamended adobe caps which were applied to the historic walls in 1992 have not caused any accelerated deterioration of the adobe wall, and until better alternatives are identified, unamended earthen caps are recommended for use at Fort Selden. Recommendations center around research into separating and quantifying the effects of natural erosion at exposed upper wall faces versus accelerated erosion caused by caps, and then further investigation into the processes by which certain capping materials cause accelerated erosion. Once these processes are better understood, different materials and designs can be tested.

Test walls 4 through 15 were used to test twelve different wall foundation treatments, measure the rate of capillary rise through the foundation, and assess the effects of moisture on the walls. Treatments ranged from traditional foundations (adobe, stone) to more modern designs (concrete stem walls, vapor barriers). To monitor moisture, thermistor soil cells were placed at intervals in the test walls. Two test walls displayed little or no basal erosion after fifteen years of exposure and no moisture retention above grade: the adobe wall with a stone foundation and the adobe wall with an adobe foundation and French drains on either side. Thus the historic stone foundations at Fort Selden should be maintained and kept clear of soil deposits and debris. In historic walls with adobe foundations moisture can be reduced by installing French drains, thus reducing basal erosion and prolonging the life of the wall. In the future, the method used to measure moisture under very dry conditions should be improved; then similar experiments can be designed to study the relative performance of these and other potentially effective wall foundation treatments.

At any earthen site, the selection of a preservation treatment should be the result of careful study of the environmental conditions and the physical, mechanical, and chemical properties of the materials used in the architecture, as well as the properties of potential repair materials drawn from both traditional and modern sources. All of this information should be filtered through the preservation philosophy and practical considerations of the persons or agency managing the site, after which a number of preservation materials or methods can be selected for testing. The methodology used for the Fort Selden Test Wall Project – Phase I is simple and straightforward, and should provide site managers with the information necessary to design a research project, evaluate the results, and select an appropriate protective coating, cap, or wall foundation treatment.

1.0 INTRODUCTION

Fort Selden was one of several small adobe forts established by the United States Army to protect settlers, travelers, and traders in the southern part of the Territory of New Mexico. The fort was constructed in 1865, briefly abandoned and then partially reconstructed in the middle of its life, and then finally abandoned in 1891. According to one source, "The doors, windows, and other hardware were removed by a contractor who reportedly was permitted to salvage the materials in payment for the removal of bodies from the post cemetery" (Cohrs and Caperton 1993: 28; Wilson and Caperton 1977: 6). Contradicting this, Army records state that the last remnant of the garrison was a detachment of troops assigned to remove the doors and windows; this detachment was withdrawn in February of 1892 (Museum of New Mexico 1971). Whichever the case, the vulnerable adobe was further exposed to the elements, hastening the inevitable effects of time and natural forces. In 1896, the fort was inspected by the General Appraiser of Abandoned Military Reservations, who had only this to say:

> The wood-work of all these buildings, which are adobe, has been removed and there is nothing left but parts of walls and piles of dried mud, all of which is worthless. There is nothing to appraise in the shape of buildings or building material. (Museum of New Mexico, 1971)

Abandoned and unattended by the maintenance that accompanies human habitation, the fort began to deteriorate rapidly. The total lack of vigas and latillas at the site suggests that these materials were also removed, probably by 1896 (no roofs are visible in photographs taken in the 1920s). Unsupported lintels collapsed, exposing the vulnerable edges of door and window openings. The tops of unroofed walls eroded because they were no longer protected. Walls were made unstable because they were no longer tied together by vigas and the weight of the roofs.

No maintenance or stabilization was recorded between 1891 and 1972. In fact, the activities of tourists, "treasure hunters," and local residents, which included riding or driving around the site, climbing to the tops of walls for photographic purposes, or conducting impromptu excavations, have most certainly hastened deterioration in a few instances. All that remains above grade are the remnants of the adobe walls and the stone walls of the prison. Below grade, the stone and adobe foundations of the walls remain intact, as do fragments of the lime plasters that originally covered the interior walls.

Today Fort Selden is located in Radium Springs, New Mexico, 17 miles north of Las Cruces. The fort was donated to the state of New Mexico in 1963, and was declared a New Mexico State Monument, under the administration of the Museum of New Mexico, in 1974. Since 1972, projects have been undertaken to stabilize and protect the adobe ruins in their found state. Stabilization treatments generally consisted of bracing unstable walls, regrading to improve drainage, inserting adobes in holes or heavily eroded areas, and applying protective coatings of unamended earth to the tops and vertical faces of the walls.

These stabilization treatments were effective but required frequent maintenance and replacement. When they could not be renewed due to constraints of time, money and manpower, deterioration of the historic walls continued. Thus the Fort Selden Adobe Test Wall Project – Phase I was conceived in an effort to find better methods and materials to protect the historic walls, and to address problems of modern earthen construction as well. The project began in 1985 with the construction of 15 adobe test walls to which were applied a wide range of protective coatings, caps, and foundation treatments. The test walls were regularly monitored through 1991 in order to document their performance over time.

1.1 SCOPE OF WORK FOR THE PRESENT PROJECT

The purpose of this project was to critically analyze and assess the results of the Fort Selden Adobe Test Wall Project – Phase I. In summary, the Scope of Work for the project included the following items (a complete copy of the Scope of Work is included in Appendix A):

- Review the design of the test wall project and the literature related to the methods and materials tested.
- Review the photographic, videographic, and written documentation of each test wall panel which was recorded on a monthly basis for approximately five years, and semi-annually for the next several years.
- Assess the current condition of each treatment applied to the test walls and assess why each treatment performed as it did.
- Conduct final photographic documentation of each treatment using the same datum points established in 1985.
- Review, analyze, and document treatments that were applied to the historic walls in the 1990s based on positive results from the 1985 test walls.
- Prepare a final report, including a synopsis of the above material, an evaluation of what was learned from the test walls, and recommendations for how the positive results might be tested for application at other earthen sites (including recommendations for further research). Also review Phase I publications to date, and assess how the findings of this report coincide or differ with their conclusions and observations.

The author was contracted by the Getty Conservation Institute to perform this work; the project manager was Erica Avrami, Project Specialist at the Getty Conservation Institute. Information on the Test Wall Project was collected during a visit to the Museum of New Mexico State Monuments office in Santa

Fe (January 2000), where all reports, correspondence, product literature, and photographic documentation are housed. During a visit to Fort Selden State Monument (March 2000), final 35mm Ektachrome slides of the test walls were taken and final condition assessments were conducted. Final 2 1/4" black and white photographs of the test walls were taken by Fort Selden State Monument staff (May 2000). In all phases of the project, the author worked closely with Michael Taylor, now Deputy Director of Museum of New Mexico State Monuments, who ensured that information was correct and provided invaluable insight into the Test Wall Project.

1.2 EXPERIMENTAL DESIGN

In response to the ongoing deterioration of the adobe walls at Ft. Selden and at other sites both historic and modern in the southwestern United States, the Adobe Test Wall Project – Phase I was conceived by Michael Taylor, then Chief of Structural Preservation Unit for New Mexico State Monuments, Museum of New Mexico. Thomas Caperton, Director of New Mexico State Monuments, was also active in the design and implementation of the project.

In the construction and preservation of earthen architecture, three protective measures are commonly employed to reduce the need for continual maintenance: 1) protective coatings on vertical wall faces, 2) caps on wall tops, and 3) foundations and other treatments at wall bases. The Adobe Test Wall Project – Phase I was designed to investigate the relative merits of different preservation techniques and materials used for protective coatings, caps, and foundations. Selection of the preservation techniques and materials for testing was made after a literature review and consultations with professionals in the adobe construction and preservation fields.

> Some of the techniques that had provided positive results in other testing regimes were incorporated into this test wall project. A few techniques that had failed in past preservation attempts were implemented in order to demonstrate the deleterious effects of such treatments. Since funds were limited, only a fraction of the innumerable methods and chemicals available to test were implemented in this experiment (Taylor 1990: 383).

A total of 15 adobe test walls were constructed for the project. Two walls were used for the protective coating experiment, one for the wall cap experiment, and twelve for the wall foundation experiment.

Protective coatings

Earthen renders without additives are the most materially compatible protective coating for earthen architecture. However, if left unroofed or otherwise unsheltered, these renders must be frequently maintained, a task which can prove impossible if time and money are limited. "For this reason [preservationists] continue to seek a suitable amended rendering for earthen walls which retards the cyclical maintenance without compromising the wall by the effects of coatings that are too rigid, impermeable, or visually obtrusive. Another ongoing endeavor has been the search for a compatible material that can be sprayed or brushed onto an earthen wall without the use of a [render]" so that the adobe coursing remains visible (Taylor 1990: 383).

Thirteen different coatings were selected to test their relative effectiveness at protecting the adobe walls. These were applied to two long walls, one oriented north-south and the other east-west in order to account for the effects of orientation and exposure. Of the protective coatings, seven were renders[1], four were spray applications, and two were roll-on applications. The sprays and roll-ons were applied over both the unrendered adobe walls and unamended earthen renders. In order to measure the effectiveness of each protective coating, the panels were monitored for color change, qualitative erosion, and quantitative erosion (see Section 3.0).

Wall caps

On unroofed adobe buildings, deterioration is often concentrated at the wall tops because of their high degree of exposure. Caps have long been used to protect these vulnerable areas, and have been composed of a wide range of materials, including unamended adobe, unamended earthen render, amended adobe, amended earthen render, cement-based render, ceramic tiles, bricks, stone masonry, and even sod and other vegetation. It is an irrefutable fact that caps protect the tops of walls and prevent them from losing height. However, some capping materials appear to accelerate the erosion of the adobe immediately beneath the cap, causing a reduction in wall width which can sometimes threaten to undermine the cap. The cause of this accelerated erosion has been attributed to moisture trapped in the adobe beneath the less permeable cap and increased surface runoff from the less permeable cap onto the soft adobe.

Test wall 3 was designed to assess the relative effectiveness of four caps at protecting the underlying adobe wall, to determine if they caused accelerated erosion at the cap/wall interface, and to compare the amount of erosion from both the capped wall tops and vertical wall faces with that of uncapped panels on test walls 1 and 2. The walls were monitored for qualitative erosion and quantitative erosion (see Section 3.0).

Wall foundations

Erosion at the bases of earthen walls is a nearly universal condition, and one that threatens to undermine walls and cause their collapse. Erosion can be caused by the backsplash of rainwater, but is usually attributed to the capillary rise of surface water and/or groundwater through the wall. The water may leach constituent minerals from the earthen materials and may also deposit harmful salts in the pores. Some salts expand and contract on wetting and drying, exerting pressure on the pore walls, causing cracks,

[1] For consistency and clarity in this report, the term render is used instead of plaster or stucco. However, the latter terms are preserved in direct quotations.

and resulting in the disintegration of the earthen material. By a similar process, moisture in the wall can freeze, thaw, and exert tremendous pressure on the pore walls during the phase change of water.

"Various methods have been used throughout history to retard the capillary rise of moisture into earthen walls. Some have proven beneficial and some detrimental to the preservation of wall bases" (Taylor 1990: 384). Test walls 4 through 15 were used to test the relative effectiveness of twelve different wall foundations at reducing capillary rise in adobe walls; these ranged from traditional foundations (adobe, stone) to more modern designs (concrete stem walls, vapor barriers). Treatments were selected "upon the basis of modern and historic practices, as well as myths, facts, arguments, and fantasies" about adobe wall foundations. In order to measure the relative effectiveness of each foundation at reducing the amount of capillary rise, each wall was monitored for qualitative erosion and moisture (see Section 3.0).

1.3 CHRONOLOGICAL HISTORY OF THE ADOBE TEST WALL PROJECT – PHASE I

The Fort Selden Adobe Test Wall Project – Phase I was intended to be a ten year project which began with construction of the test walls in 1985. The methodology and preliminary results of the project were presented at two international conferences on earthen architecture in 1987 and 1990. The later conference, commonly referred to as Adobe 90, was convened in Las Cruces, New Mexico, and the test walls were an integral part of a discussion on adobe preservation research presented at that conference. The test walls were monitored until 1991, at which time the experiment was largely concluded. Final monitoring and assessments of the walls were conducted as a part of this project.

Phase II and Phase III of the Fort Selden Adobe Test Wall Project were conducted under the aegis of the Getty Conservation Institute from 1988 to about 1994. The Phase II experiments were designed by Neville Agnew of the Queensland Museum, Australia, and later the Getty Conservation Institute (GCI); P.G. McHenry, AIA; and the GCI (Agnew 1990). The new adobe walls were located west of the Phase I test walls and east of the historic ruins, and were designed to test a range of chemical consolidants, shelters, drainage techniques, and structural reinforcement designs. Phase III was designed and implemented by Charles Selwitz, consultant to the GCI, and involved applying chemical consolidation treatments to the historic walls. The history and results of the Phase II and Phase III projects will be compiled at a later date.

1984

- In response to ongoing deterioration of the adobe walls at Ft. Selden and at other historic and modern sites in the southwestern United States, the Adobe Test Wall Project is conceived by Michael Taylor, then Chief of the Structural Preservation Unit for New Mexico State Monuments, Museum of New Mexico. Thomas Caperton, Director of New Mexico State Monuments, is also active in the design and implementation of the project, and presents a proposal and budget to the State government for consideration (Caperton 1984).

- In order to identify potential preservation methods and materials for use on the test walls, professionals in adobe preservation and construction are consulted and a literature search is conducted. Of particular relevance were projects conducted by Dennis Fenn for the National Park Service at Chaco Culture National Historical Park and Bent's Old Fort National Historic Site (Fenn and Niebla 1981).

1985

- In May, Taylor prepares "Specifications for the Fort Selden Stabilization and Test Wall Project," a two part project which involves 1) extensive repairs to the historic walls using unamended earth and 2) the design and construction of the test walls (Taylor 1985). Detailed specifications and construction drawings for the test walls are included in the second part of the report, and were prepared by Paul Graham McHenry, Jr., AIA (McHenry n.d.).
- The specifications for the test wall construction are put out to bid, and the contract is won by Rio Abajo Archaeological Services of Polvadera, New Mexico. This company is under the direction of William Gossett and Cye Gossett, both of whom are instrumental in the test wall construction. A written narrative is prepared which summarizes the construction of the test walls and documents daily activities from project inception, August 28, to conclusion, November 8 (Gossett and Gossett 1985).
- In late August and early September, the proposed site for the test walls is surveyed for surface artifacts; the site is about 500 feet east of the historic ruins. The area is then cleaned of vegetation and trenches are dug for the test wall footings. Supplies and materials for construction are collected at the site.
- Construction of the test walls begins in mid-September and is largely complete by November 8. The third and final coat of earthen render for panels 1N9, 1S9, 2E9, and 2W9, which is to be amended with agave juice, will not be applied until late March 1986. The dial switches used for reading the soil cells in test walls 4-15 will be installed in March as well (Taylor 1986b).
- The walls are also photographically documented for the first time with 35mm Ektachrome slide film and 2 1/4" black and white film. The walls are photographically documented every two months through January 1990; from June 1990 through June 1991 they are photographed every 4 months (Anon. 1991a, 1991b, 1991c, 1991d, 1991e, 1991f, 1991g; copies of the black and white photographs are included in Appendix G). No further slides or photographs are taken until the spring of 2000, as a part of this report (Appendix H).
- In order to record the climate at the site, a weather station is installed just southwest of test wall 1 which records wind speed and direction, temperature, relative humidity, and

precipitation. Daily measurements are recorded from October 1985 through February 1990 (Anon., 1985-1990).

1986

- In mid-January, several structural cracks develop in test walls 1 and 2. This may be the result of natural settling or of seismic activity, which was recorded in the Las Cruces area at about this time (Taylor 1986b).
- At the end of March, the third render coat is applied to panels 1N9, 1S9, 2E9, and 2W9; it is amended with agave juice (Taylor 1986b).
- In November the first "Fort Selden Test Wall Status Report" is prepared, which details the project goals, test wall design and construction, basic weather data for 1985-86, and the performance of each treatment to date (Taylor 1986c). This report is distributed to professionals in the adobe preservation and construction fields for review and comment.
- The walls are photographically documented in January, March, May, July, September, and November. On January 25 and March 20-21, the test walls are recorded and described on videotape (Taylor 1986a and 1986b). In November, on their first birthday, the walls are again recorded and described on videotape (Taylor 1986d).

1987

- In October, the preliminary results of the test wall project are presented at the 5th International Meeting on the Conservation of Earthen Architecture, held in Rome. The paper prepared for the conference, "Fort Selden Test Wall Status Report," is published in the conference proceedings (Taylor 1988). It is also proposed that the next international conference be held in Las Cruces, New Mexico, in 1990.
- In November the "Fort Selden Test Wall Project Second Annual Status Report" is prepared, which again details the project goals, test wall design and construction, basic weather data for 1985-87, and the performance of each treatment to date (Taylor 1987b). As with the first report, the second report is distributed to professionals in the adobe preservation and construction fields for review and comment. Although the intention was to prepare an annual report for each year until 1995, this was the last official status report prepared for the project. A paper presented at the Adobe 90 conference is essentially a status report for that year (Taylor 1990).
- The walls are photographically documented in January, March, May, July, September, and November. On July 30, the test walls are again recorded and described on videotape (Taylor 1987a). No further videotapes were recorded.

- In December, construction begins on the test walls for the Fort Selden Test Wall Project – Phase II.

1988

- The Phase I walls are photographically documented in January, March, May, July, September, and November.
- Construction and testing of the Phase II test walls commences.

1989

- The Phase I walls are photographically documented in January, March, May, July, September, and November.

1990

- The 6th International Conference on the Conservation of Earthen Architecture, or Adobe 90, is convened in Las Cruces, New Mexico, from October 14-19. The conference is sponsored in part by Museum of New Mexico State Monuments and the GCI. A paper on the Phase I test walls, "An Evaluation of the New Mexico State Monuments Adobe Test Walls at Fort Selden," is presented, as are three papers on the Phase II walls (Taylor 1990, Agnew 1990, Coffman et al. 1990, and Selwitz et al. 1990). A visit to the test walls at Fort Selden is an integral part of the conference.
- The Phase I walls are photographically documented in January, June, and October.

1991

- The Phase I walls are photographically documented in February and June. Due to changes in staffing, no further documentation of the walls is conducted until 2000, as part of this project.

1991-1999

- The walls are periodically visited and described by Michael Taylor in field notes.

2000

- The author is contracted by the Getty Conservation Institute to summarize and assess the Fort Selden Test Wall Project – Phase I, and also to take final slides and photographs of the walls.

2.0 DESIGN AND CONSTRUCTION OF ADOBE TEST WALLS

A total of 15 walls were constructed for the Adobe Test Wall Project – Phase I (Figure 1). Two of the walls were used for the protective coating experiment, one for the wall cap experiment, and twelve for the wall foundation experiment (Figure 2). The project specifications were prepared by P.G. McHenry, AIA (McHenry n.d.), and the test walls were constructed by Rio Abajo Archaeological Services (Gossett and Gossett 1985). The specifications and the construction narrative are included in Appendix B.

2.1 TEST WALL CONSTRUCTION

Fort Selden is located just east of the Rio Grande, on a gravel bench about 15 feet above the floodplain. The Phase I adobe test walls were constructed on the same bench about 500 feet east of the historic ruins (see Figure 1). Construction of the test walls began on September 13 and was largely completed by November 8, 1985. (The exception was the final coat of amended render for panel 9 on test walls 1 and 2, which was not applied until late March of 1986.)

> Construction was begun by cleaning the building site through removal of vegetation and artifacts… After the clearing, speed leads were set… to delineate the foundation trenches. A ditch witch was then used to excavate all foundation trenches. Additional shaping and cleaning of the trenches was completed by hand.
>
> [Weather], overall, was very good, although during the rainy season [test wall 12] toppled due to moisture collecting along an open trench at the base of the wall. Additionally, cloudy and moist weather slowed drying times, particularly on the north face of test wall 1. Warm, windy weather, on the other hand, seemed to enhance (speed up) overall drying time for all plaster applications. Heat, rather than cold, was a major weather factor, in that plaster on the south and west walls dried too quickly, thus creating large cracks and peeling. Freezing temperatures were never a problem even for the chemical applications during this fall season in such low latitudes (Gossett and Gossett 1985: 5-6, 17).

All of the test walls were constructed of unamended adobes laid in unamended earthen mortar; the adobes measured 14” x 10” x 4”. Unamended adobes were not available in Las Cruces, and instead were obtained from Sr. Faustino Rios, Sindicato Gremial de Ladrilleros (C.R.O.C) of Juárez, Mexico.

> Also, all soil used for mortar and plastering was obtained from Sr. Rios as well. Use of soil from the same source as the adobes was thought to [ensure] a consistency in the construction technique. However, variation in the soil from the same source differed in clay/sand content and color… A total of 3125 adobes and 25 cubic yards of adobe soil were used to construct the test walls (Gossett and Gossett 1985: 2).

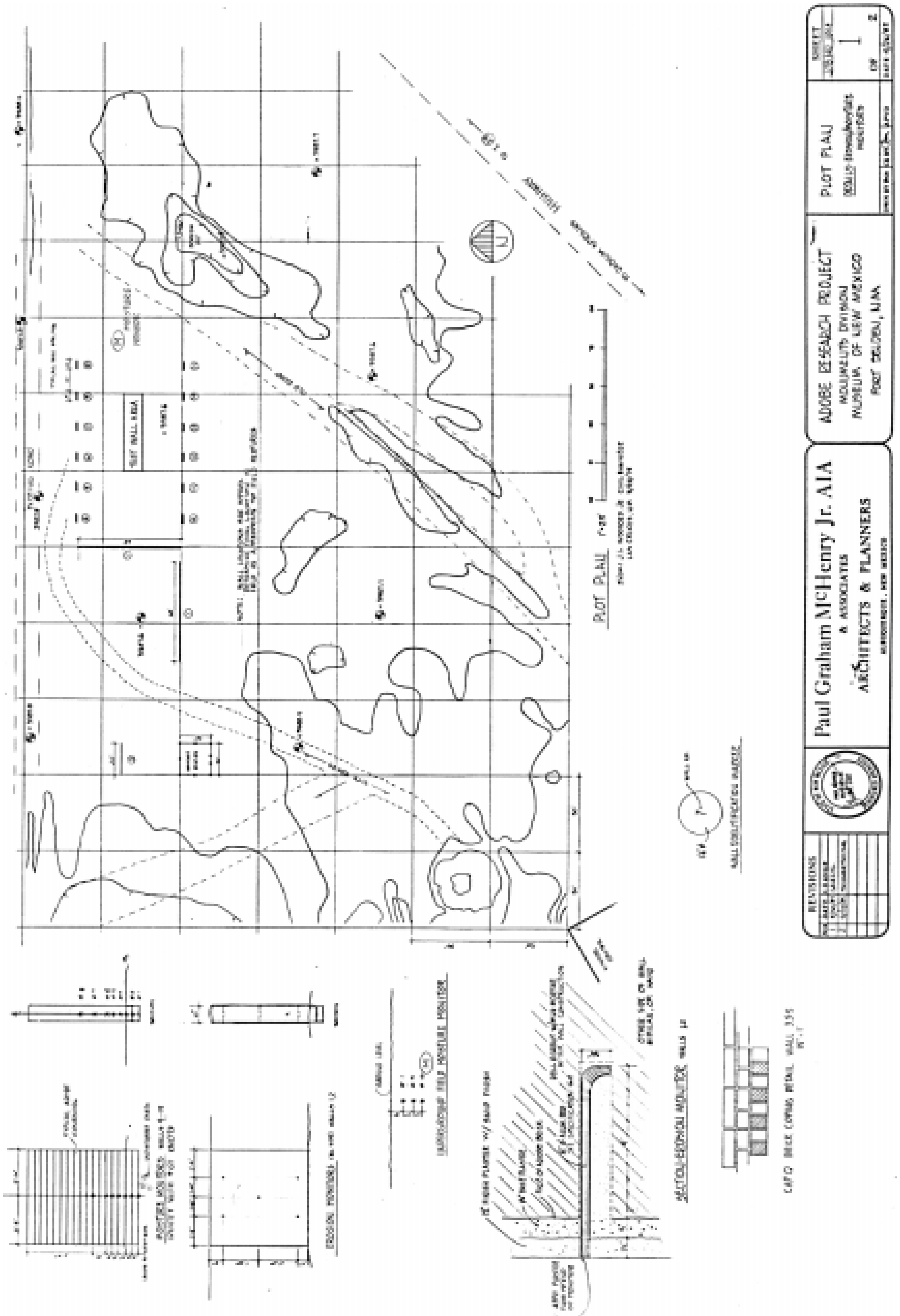

Figure 1. Site plan for the Fort Selden Adobe Test Wall Project – Phase I

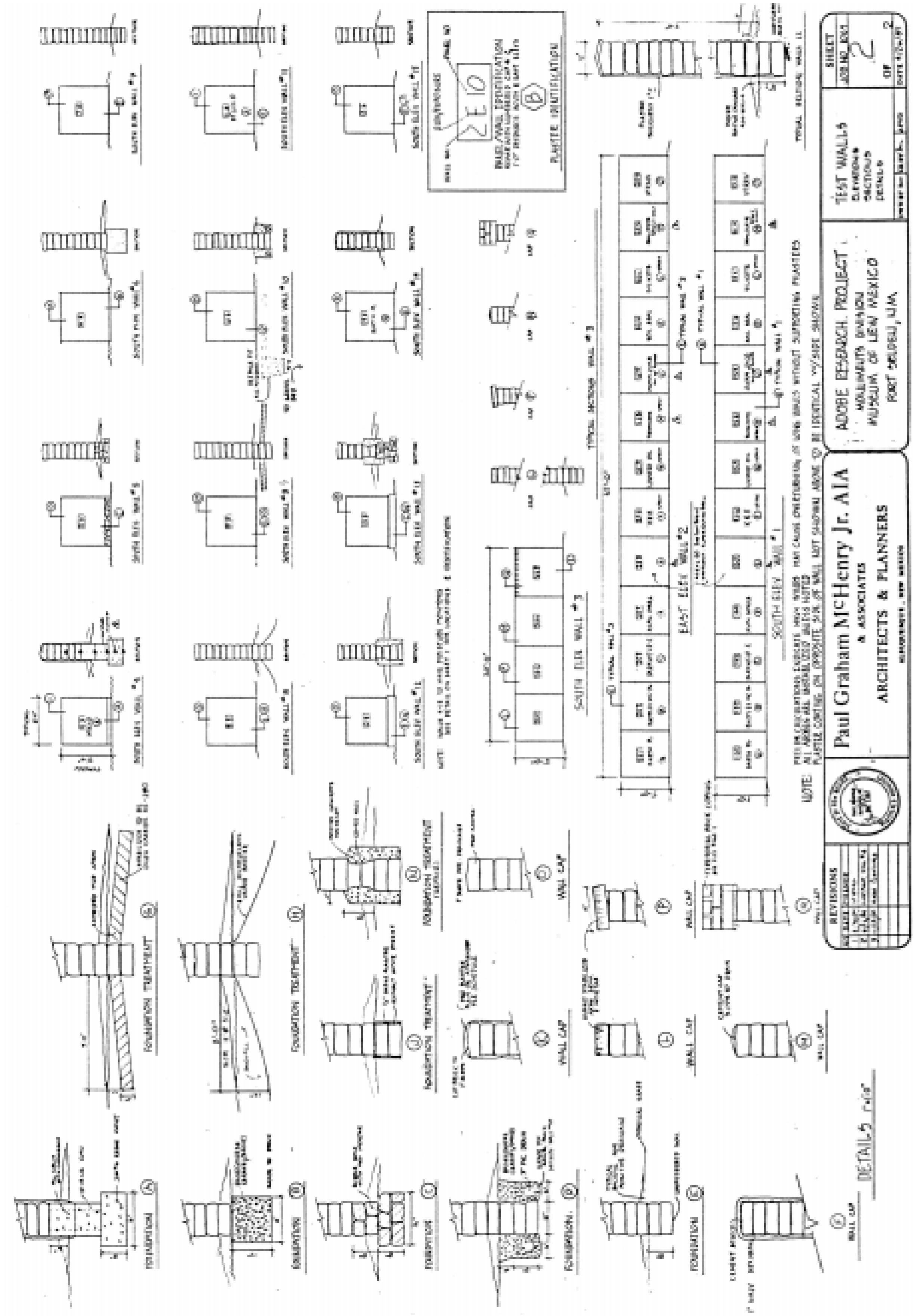

Figure 2. Elevations, sections, and details of test walls constructed for the Fort SeldenAdobe Test Wall Project – Phase I.

Apparently, the soil for the adobes, mortars, and renders was obtained west of Juárez, near the city dump (Taylor 1986a). Most of the other materials for the project were obtained locally, although a few items were purchased in Albuquerque.

> Other materials required to build the walls were plaster sand to mix with the adobe soil (15 cubic yards); angular limestone and rhyolite rock (1 cubic yard); river cobbles, averaging 3 inches in diameter, (1/4 cubic yard); 3/4 inch gravel (1/2 cubic yard); concrete blocks (7 8x10x16 and 2 8x10x8); 4 inch perforated PVC pipe (12 ft.); roof coating (1 gal.) [for Test Wall 15]; stucco (4 bags); lime (2 bags); poultry netting (25x5 ft.); stabilized adobe bricks (10); red patio bricks (75). All materials were obtained locally except for the stabilized adobe bricks which were purchased in Albuquerque, N.M. The river cobbles and the foundation rocks were located about 1 mile north of the Fort along the river. They appear to match the historic construction materials in the foundations of the Fort…
>
> Labor for the test walls consisted of 2 full-time experienced masons and 1 full-time assistant who mixed plasters and mortars, as well as kept the area clean. The project director [William Gossett], also an experienced mason, worked approximately one-half time; the other half-time being spent on purchasing and obtaining supplies, completing as-built photography, keeping a daily log, and supervision (Gossett and Gossett 1985: 2-5).

As the adobe walls were constructed, head joints were left open where renders were to be applied (Gossett and Gossett 1985: 10). The project specifications required that all renders be applied in two layers, each 1/2” thick. However,

> we discover that we must let first plaster coat get completely dry before adding second coat (drying time at least 48 hours of dry-hot weather). The original plaster coat thickness called for in the contract (1/2 inch) is too thick. When the second coat was applied, the two then cracked and fell away from the walls. In order for the plaster to adhere to the walls the coats were reduced to 1/3 inch in thickness, thus requiring three coats… Because of the differential drying rates on the four wall sides the panels are in various stages of preparation (some have 1 coat, some have two coats, some are cracked and must be completely replastered) (Gossett and Gossett 1985: 12).

Thus all earthen renders were applied in three layers, each approximately 1/3” thick. Prior to each new coat, the wall surface was prepared with a light spray of water. Renders were troweled onto the wall and, after drying, shrinkage cracks were repaired with a sponge or float treatment (Gossett and Gossett 1985: 13; McHenry n.d.: 7). Soil for the final coat was screened to remove particles larger than 1/8” (McHenry n.d.: 7; Gossett and Gossett 1985: 13). If an additive was used, it was usually added to all three layers. If a spray or roll-on coating was used, the panel was first rendered with three layers of unamended earth and the treatment was applied over the final coat. In some instances, the spray or roll-on coating was applied directly to the adobe bricks.

To prevent moisture from puddling on the walls, all wall tops were sloped approximately 1 inch from the crest to each side of the wall; the treatments for the caps on test wall 3 were somewhat different and are discussed in further detail in Section 5.0 (McHenry n.d.: 5). After construction, a positive drainage was established away from all of the test walls (Gossett and Gossett 1985: 9).

Identification markers were placed one foot out from the center of each wall or wall panel. The markers were constructed by securing rebar in the ground and attaching an aluminum cap to the top which was stamped with the wall identification number. These markers are still in place, although many are buried in deposits of soil and sand.

Further construction details, as well as information on the individual protective coating, cap, and foundation treatments applied to each test wall, are discussed thoroughly in Sections 4.0, 5.0, and 6.0.

2.2 SOIL ANALYSIS

The project specifications required that the adobes be unamended and that the soil used for mortar and renders come from the same source (McHenry n.d.: 5, 6). As mentioned above, unamended adobes were only available in Juárez, Mexico, and three truckloads of soil were purchased from the same supplier. Moving loads of loose soil through U.S. Customs presented problems, and there was no control over the source and kind of soil delivered (Gossett and Gossett 1985: 17).

Initially, the soil from Juárez was mixed 1:1 with sharp sand for mortar and render applications. About one third of the way through the project, however, a new load of soil was delivered which seemed to have a higher clay content than the original. A mix of 2:3 soil to sand was then tested, which proved adequate for the renders (Gossett and Gossett 1985: 12).

Four samples from the Fort Selden test walls were analyzed for particle size, Atterberg limits (liquid limit, plastic limit, and shrinkage limit), soil classification, and electrical conductivity. The samples were taken from the following sources:

- #5964: from truckload #2 of Juárez soil
- #5965: from truckload #3 of Juárez soil
- #5966: from the sand used to temper the soil for renders and mortar
- #5967: from an adobe from Juárez.

The results of the tests are reported in Table 1; the original test results are included in Appendix C.

The soils in truckload #2 (classified as a clay) and truckload #3 (classified as a silt-clay) are similar in particle size distribution and plasticity index (PI). These truckloads were predominantly used for render applications. No data was available for truckload #1 of soil, which was predominantly used for mortar. Based upon the observations of the construction contractor and the fact that only 1 part sand was added per 1

Table 1. Results of soil analyses performed on four samples of material used in the Fort Selden Adobe Test Wall Project – Phase I.

Sample #	Particle size (sieve) (% passing)			Particle size (hydrometer)			Soil type†	Atterberg limits††				Electrical conductivity‡ (mmHos/cm)
	#10	$40	#200	% sand	% silt	% clay		LL	PL	PI	SL	
5964 soil #2	--	--	58.4	51.5	24.0	24.4	CL	25	17	8	17	2.17
5965 soil #3	99.7	97.8	51.4	59.6	18.0	22.4	ML-CL	23	17	6	17	0.80
5966 sand	98.2	48.0	2.9	96.8	0.5	2.7	SP	--	--	NP	--	--
5967 adobe	95.7	88.8	47.3	62.6	19.0	18.4	SM	21	18	3	15	2.16

† Unified Soil Classification System (USCS)
CL = inorganic clay of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
ML = inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.
SP = poorly-graded sands, gravelly sands, little or no fines.
SM = silty sands, sand-silt mixtures.
†† LL = liquid limit, PL = plastic limit, PI = plasticity index, SL = shrinkage limit
‡ Electrical conductivity readings were taken from saturated soil pastes.

part soil, soil in the first truckload presumably contained more sand.

Soil truckloads #2 and #3 are high in clay-sized particles but have low plasticity indices, which indicates that the clays are of low plasticity and/or that many of the clay-sized particles are not clay minerals. Although the plasticity index indicates that the soils may be relatively non-cohesive, the presence of calcite in the soil may serve as a cement and make up for the low mineralogical clay content of the soils (see below).

The sand is classified as poorly graded, well sorted sand, meaning that much of the sand is about the same grain size. However, it is well-graded within the range in which it occurs, which would allow the grains to be tightly packed and thus increase the compressive strength of the render (see Appendix C). Of equal importance is the shape of the sand grains: angular grains resist compressive forces better than rounded grains (Agnew 1987: 26). No grain shape was recorded, but because the sand was labeled a “sharp sand” and a “plaster sand”, it is assumed that the grains were angular and that the sand was an appropriate admixture to the soil (Gossett and Gossett 1985: 2).

The adobe is classified as a silty sand and contains about 63% sand, 19% silt, and 18% clay, falling well within the recommended parameters for particle size distribution for a good adobe (50-75% sand and 9-28% clay) (Agnew 1987: 26). Its shrinkage limit and plasticity index are lower than the soils used for protective coatings, although the addition of sand would make the Atterberg limits for the soils more similar to the adobe.

In a separate set of tests, a second adobe sample was analyzed for particle size using sieve and sedimentation procedures (Agnew et al. 1988). The results indicate that the particle size distribution is 54%

sand, 36% silt, and 10% clay (no classification system is noted and different definitions of sand, silt, and clay sized particles may have been used, but differences in the systems are small and the figures are probably comparable). This second sample also falls within the recommended limits for adobe, but is different than the first adobe sample. It is quite common to have a high degree of variability within a single adobe, let alone between two adobes in a wall, and these mixed results are not surprising.

The second adobe sample was also analyzed for mineralogical composition using x-ray diffraction (Carmichael 1987). Minerals were identified in both the bulk sample and the clay-sized fraction (less than 2 microns in diameter) of the sample. The results were as follows:

> Fort Selden Test Wall (bulk) - Dominantly quartz with minor calcite, plagioclase feldspar and accessory potassium feldspar, mica and amphibole.
> Fort Selden Test Wall (clay) – Illite/Smectite (random interstratification) 61%, Mica/Illite 26%, Kaolinite 13%.

Thus the adobe was composed largely of quartz sand, as is recommended. Clays were predominantly mixed illite and smectite, which exhibit low to moderate swelling in the presence of water, and mica and illite, which are dimensionally stable in the presence of water. These clays are good for use in adobes.

The light color of the adobes and soil is due to the presence of calcite, which is a very common constituent in soils in arid regions. The calcite may also act as a cement and add strength to the earthen materials. When calcite-rich soils are wetted during the manufacture of adobe, mortar, or render, some of the calcite dissolves and, as water evaporates, reprecipitates. As the pores of the earthen material become unsaturated, water becomes limited to thin films on the grain surfaces and, due to capillary forces, to constrictions where grains contact one another. As drying continues, the pore water solution becomes supersaturated with respect to calcite and eventually calcite precipitates, cementing the grains together. Calcite in the soil may also stabilize the clay minerals because calcium ions from the dissolution of calcite inhibit the swelling of clays.

2.3 CONCLUSIONS AND COMMENTS

The Fort Selden Adobe Test Walls – Phase I were well-designed and constructed, and good records were kept in the form of construction specifications (McHenry n.d.), a construction narrative and summary (Gossett and Gossett 1985), and an oral interview with the construction project director (Taylor 1986a). The following comments include ways in which the test walls might have been improved to provide more accurate data. It is well understood that constraints both predictable and unforeseen greatly influenced the design and implementation of this (and every) project, and the comments suppose an ideal world with no constraints imposed.

The adobe, soil, and sand used for the project were of good composition for earthen construction. However, making the adobes on site with known materials and under controlled conditions would have reduced variability in adobe composition and weathering characteristics. Quarrying soil for the protective coatings from a local source, or manufacturing it from known materials, would help to reduce variability in protective coating composition and make data more statistically comparable. Also, increasing the width of the test walls (to at least two adobes) would have made them more like historic walls both in construction and weathering characteristics. Several of the walls were toppled, presumably by wind, and wider walls might have withstood this. In addition, wider walls have different thermal properties than narrower walls, and the weathering of the walls in reaction to thermal stress, humidity, capillary rise, etc., might have been affected by width.

As regards material analysis, characterizing the physical and chemical composition of more samples of adobes and unamended protective coatings would have created greater statistical accuracy and would allow for a better understanding of the weathering characteristics of the materials and their interactions with the various additives used in the renders. Water vapor transmission measurements of the adobes and especially the unamended protective coatings would have allowed for an increased understanding of the weathering characteristics of the walls and of the effects of various additives on the vapor transmission of the protective coatings.

3.0 MONITORING OF ADOBE TEST WALLS

As a part of the Fort Selden Adobe Test Wall Project – Phase I experimental design, a monitoring program was designed and implemented in order to measure the immediate environment around the test walls; color change, qualitative and quantitative erosion in test walls 1 and 2 (protective coatings); qualitative erosion in test wall 3 (wall caps); and qualitative erosion and moisture content in test walls 4-15 (wall foundations). The monitoring procedures are described in detail below. Data obtained from color monitoring, erosion monitoring, and moisture monitoring are presented and discussed in the relevant sections later in the report.

3.1 ENVIRONMENTAL MONITORING

Environment is the critical factor in the deterioration of the adobe test walls. The amount and kind of precipitation which hits the walls or rises through them, the intensity and the cycling of temperatures, the direction and speed of prevailing winds in combination with the moisture or particulate load which they carry: it is the complex interaction of these phenomena, in combination with the specific treatment applied, which determine the type and rate of loss.

The Monument's water supply well is located in the floodplain and the depth to water is nine feet. The Phase I adobe test walls were constructed on a gravel bench about 15 feet above the flood plain and 500 feet east of the historic ruins; the water table beneath the bench is probably at least twenty feet below ground surface. Thus the test wall site is not affected by flooding from the river and the water table is too deep for capillary rise to affect the walls. Thriving xeric vegetation at the site (creosote bush and four-winged saltbush) and the failure of introduced phreatophytes (cottonwood trees planted around the parade ground of the fort) confirm that the water table is well below the ground surface. The cottonwood trees are irrigated; this may impact the historic walls but does not affect the test walls.

In terms of macroclimate, Fort Selden is located in the arid Chihuahuan desert at an elevation of 3990 feet above sea level. Temperature and precipitation have been recorded at a station 13 miles from the site since 1870. The average annual maximum temperature (1870-1983) is 76.4˚ F and the average minimum temperature is 43.9˚ F. There are an average of 97 days a year with temperatures over 90˚ F and 100 days with temperatures at or below freezing. However, precipitation is low during the potentially frosty months, moderating the threat of freeze-thaw cycling in the adobe walls. The mean annual precipitation is 8.49 inches, and the rainy season is from July to mid-September, during which 54% of annual rainfall is received (Caperton 1990: 209). The **Soil Survey of Dona Ana County Area, New Mexico** (Bulloch and Neher 1980) contains additional information derived from data recorded at New Mexico State University, in Las Cruces:

> On the average, 42 thunderstorms occur each year, most of them in April through October; a few are accompanied by hail. Dust storms are most frequent in spring when winds are strong and soils are dry, but soil blowing can occur briefly just before a thunderstorm.Snowfall is generally light... Average annual snowfall ranges from 2.5 to 5 inches at lower elevations... In about 1 year in 3 there is no measurable snowfall... [An] average of less than 1 day in winter has 1 inch or more of snow. The average depth of

> snow cover on these days is 2 inches, but rarely does the snow cover last for 2 consecutive days. (Bulloch and Neher 1980: 1-2)

Between 1914 and 1943, the average relative humidity was 61% at 7:30 a.m. and 33% at 5:30 p.m.; the highest humidity occurred in the winter months, the lowest in the spring months. Cropland irrigation increases the relative humidity in the area. Between 1914 and 1967, the average wind speed was 5.9 mph; the strongest winds occurred in the spring months. Prevailing winds were out of the north in November-January, out of the northwest in February, out of the west in March-May, and out of the southeast in June-October (Bulloch and Neher 1980: 102).

As part of the Adobe Test Wall Project – Phase I, a single weather station was installed just southwest of test wall 1 to measure the local climate. The instrument was a WeatherMeasure Model WS755 Mechanical Weather Station, which recorded wind speed and direction, temperature, relative humidity, and precipitation. It was manufactured by WeatherMeasure Corporation, of Sacramento, California. This weather station was in addition to an existing weather station at the fort, which was located north of the Hospital (Feature 1) on the location of an historic weather station and which recorded temperature and precipitation.

At the test wall weather station, daily measurements were recorded from October 23, 1985, through February 28, 1990 (Anon. 1985-1990). Unfortunately, the instrument may not have been calibrated correctly and/or was malfunctioning, and the data for temperature, humidity, and possibly wind speed and direction may not have been correct (Taylor n.d.). Data for temperature recorded at the Hospital weather station was more accurate. In addition to the weather stations at the fort, comprehensive climate data is available for Las Cruces. This data is probably quite valid for Fort Selden, although the mountains just west of the fort may alter wind speeds and directions somewhat.

Based on data from the Hospital weather station, annual precipitation and days of potential frost are presented in Table 2. During the four years that weather was monitored at the fort, precipitation was above normal or average. Temperatures dropped below freezing on up to one-third of the days in each year, making damage from freeze-thaw cycling very possible. Accelerated weathering may have occurred in December, when relatively high precipitation, high relative humidity, and low temperatures coincided.

Table 2. Precipitation and frost days measured at Fort Selden State Monument, 1985-1989.

Year	Precipitation	Frost days
November 1985 – November 1986	15.08”	97
December 1986 – November 1987	10.68”	121
December 1987 – November 1988	13.08”	107
December 1988 – November 1989	7.52”	124

As regards wind speed and direction at the site,

> It is apparent from the erosional rates of the walls and the weather data compiled that the damaging summer rain storms come from the west and southwest. Winds do, however, often come out of the south, southeast, and east, and occasionally from the

> north. The spring is the windiest time of the year, with strongest winds occurring in March with gusts up to 60 miles an hour (Taylor, 1987b: 38).

But the degree to which different aspects of the weather contribute to deterioration and their interaction with other factors is a study in itself, and was not the primary goal of the Adobe Test Wall Project. In order to truly understand the microclimate around the test walls and the way in which it affected the rate of deterioration, a number of instruments to monitor temperature, humidity, and wind speed and direction would have to be installed in or on all faces of the test walls. Temperature and moisture were monitored in this way for the GCI Phase II test walls, and information on microclimate may be available when the results of that study are published.

Based upon the above information, the most threatening macroclimatic conditions are the heavy, albeit brief, summer rains; the strong, particulate-laden, westerly winds of spring; and the wet and cold month of December. Large fluctuations in daily temperatures and strong temperature gradients on the opposite sides of walls, alone and in combination with relatively high humidity, probably also accelerate the rate of deterioration.

3.2 COLOR MONITORING

Throughout the course of the project, each panel in test walls 1 and 2 (protective coatings) was monitored for color change. Monitoring was conducted at 4 months, 12 months, 24 months, and 172 months (14 1/3 years) years after application of the protective coatings. The color of the protective coatings was characterized using Munsell Soil Color Charts, a standard color notation system which provides an alpha-numeric notation of hue (the amount of red, yellow, blue, green, etc., in the color), value (the location of the color between pure white and black), and chroma (the amount of gray in the color). All Munsell matches were made under natural light and in full sun, and were taken from the south and east faces of the panels. All monitoring was conducted by Michael Taylor with the exception of the final color measurement, which was conducted by the author.

3.3 QUALITATIVE EROSION MONITORING

To record qualitative erosion in all 15 of the test walls, the walls were photographically documented using 35mm Ektachrome slide film and 2 1/4" black and white film. Photographs were taken from datums marked with rebar, set 124" back from the center of each panel or wall. The walls were documented every two months through January 1990; from June 1990 through June 1991 they were photographed every four months (Anon. 1991a, 1991b, 1991c, 1991d, 1991e, 1991f, 1991g; copies of photographs are contained in Appendix G). No further slides or photographs were taken until March and May 2000, as a part of this report (see Appendix H). All slides and photographs were taken by the Fort Selden State Monument staff with the exception of the March 2000 slides, which were taken by the author.

For test walls 1 and 2 (protective coatings), qualitative erosion was visually assessed in the field six times during the project, in November 1985, March 1986, November 1986, November 1987, October 1990, and March 2000. All assessments were conducted by Michael Taylor with the exception of the final assessment, which was conducted by the author. Erosion was described with a standard system:

5.0 = Very little erosion4.0 = Little erosion3.0 = Moderate erosion2.0 = Serious erosion1.0 = Very serious erosion

An example of each level of erosion is provided in Figure 3. In general, a protective coating is no longer effective once it displays moderate erosion (3.0). Based on these six assessments, an erosion index was calculated for each protective coating panel as a part of this report. The number was derived by taking the average erosion level from each assessment and then taking the average of those averages. The erosion index can range from 1.0 (very serious erosion) to 5.0 (very little erosion).

3.4 QUANTITATIVE EROSION MONITORING

To record quantitative erosion in test walls 1 and 2 (protective coatings), five 5.5” long, 0.25” diameter aluminum rods were placed in each protective coating panel, two at 15.24 cm (6.0”) above grade, one in the center at 76.20 cm (30.0”) above grade, and two near the top at 132.08 cm (52.0”) above grade (see Figure 1). These were installed by drilling holes in the adobe, inserting the rods, and then packing the

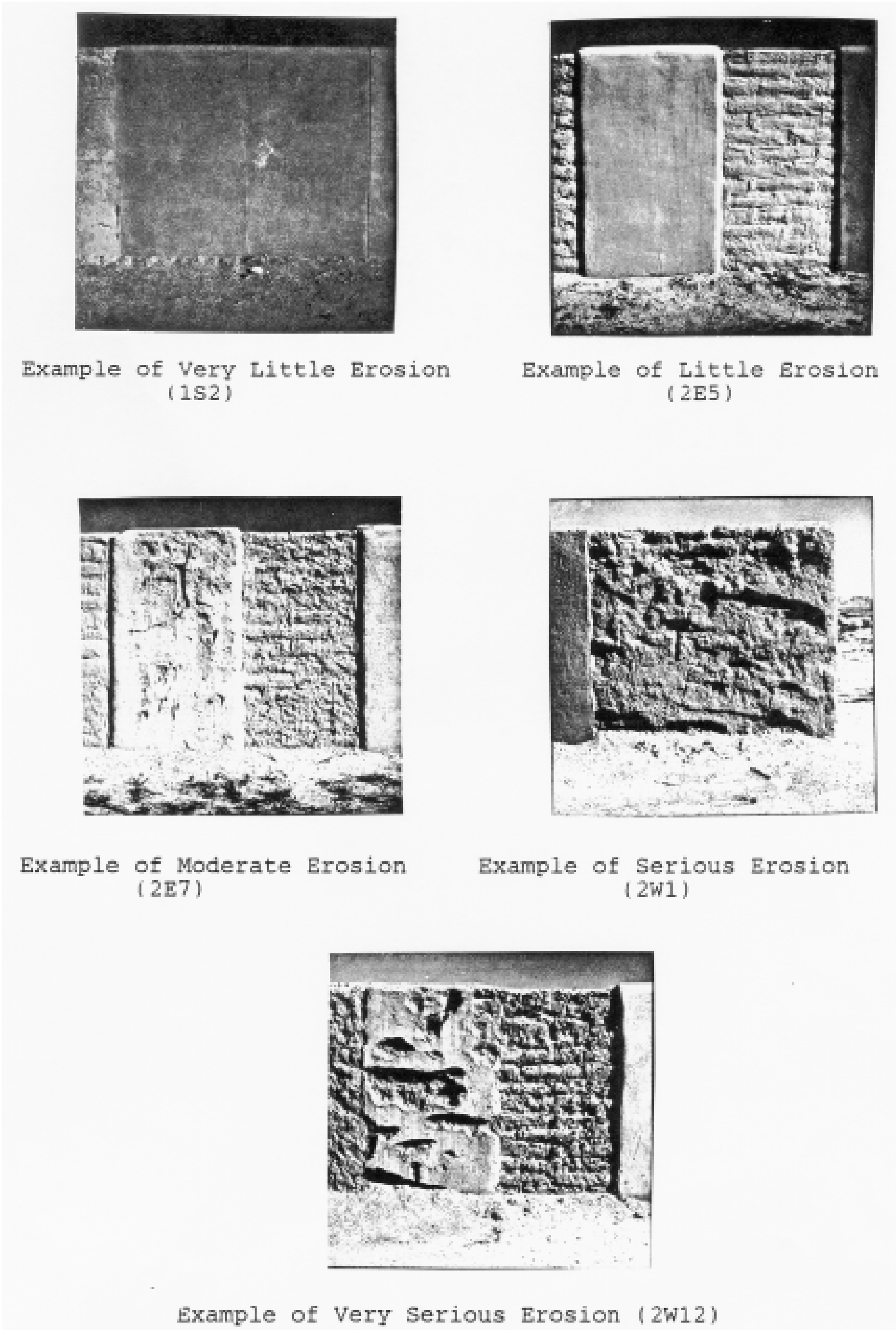

Figure 3. Illustrations of qualitative levels of erosion used to assess test walls 1 and 2 (from Taylor 1986c)

drilled hole with earthen mortar. The final layer of each protective coating was brought flush with the ends of the monitoring rods. The monitoring rods tended to work loose in the walls and because of this, no erosion measurements were recorded until March 2000. The data is presented and discussed in Section 4.14; all measurements should be considered approximate.

Quantitative erosion in test wall 3 (caps) was monitored three times. After one year of exposure, the maximum depth of erosion in the first adobe beneath each cap was recorded. After nine years of exposure, the average erosion at the adobe/cap interface and the average erosion at 20 cm beneath the cap were recorded. After about fifteen years of exposure, cross sections were measured through the two remaining caps and compared with a cross section measured through an uncapped wall. The data is presented and discussed in Section 5.0.

3.5 MOISTURE MONITORING

To monitor moisture in test walls 4-15 (foundations), thermistor soil cells (composed of two electrodes) were placed at intervals in the test walls.[2] The cells were Soil Moisture Monitor Cells, Type MC-314, and were read with a moisture meter, Type MC-300. The equipment was manufactured by Soiltest, Inc., 2205 Lee St., Evanston, IL 60202 (McHenry n.d.: 13). Eight cells were placed in test walls 4-9 and 11-15, nine cells were placed in test wall 10; these were aligned up the center of the wall, 2.5' from each wall end. In test walls 5-15, the first cell was placed below the first course of the foundation; the next five cells were placed between each adobe course, at 4" intervals. The next two cells were placed between every second course of adobe, at 8" intervals, ending at about the center of the wall (see Figure 1). In test wall 4, the second cell was placed at the top of the concrete stem wall (6" above grade) and the cells were placed as usual above that. The 6.0' wire leads on the cells extended from the center of the wall out to the west, where they were

> …placed in a central wiring harness through 3/4 inch PVC pipe near ground level and into a central waterproof switch box for protection and accessibility. The switch box housing pedestal is secured in 6 inches of cement, 1 ft. below the present ground surface and 6 inches out from the west end of the walls.
>
> The switch boxes are heavy duty plastic, in this case Carlon brand. The boxes consist of two parts; the dial switch housing and the hinged protective cover. A twelve position dial switch and two female banana jacks are attached to the hinged covered front plate so that each turn of the dial knob will actuate each level of moisture monitors up the wall for resistance readings…
>
> Moisture monitor readings, beginning with the knob arrow at 12 o'clock, are taken by insertion of the positive (red) and negative (black) Ohm meter connectors into the front

[2] The thermistor soil cells are referred to as sensors in much of the original documentation. This terminology is preserved in direct quotations.

> plate female jacks… The dial is then turned clock-wise for each individual moisture monitor reading from bottom to top in the wall (Gossett and Gossett 1985: 15-16).

Three additional cells were placed in the ground between test walls 9 and 15, at the east end of the site, to monitor background moisture and serve as a control (see Figure 1).

The thermistor soil cells were read about once a week from December 1985 through January 1988 and the readings were recorded on standard forms (Anon. 1985-1988). If precipitation occurred, the cells were read at the end of the precipitation event and daily thereafter until readings reached an equilibrium. Each cell measured the amount of resistance an electrical current encountered between two electrodes (from 0 x 10,000 ohms at saturation to 200 x 10,000 ohms under very dry conditions). The wetter the wall, the less resistance recorded on the Soil Moisture Meter. Resistance is also a function of salinity and temperature, but soil salinity is fairly constant through time and the moisture meter automatically corrects for changes in temperature. The data is discussed in Section 6.0.

The thermistor soil cells were never calibrated for the specific soil type in the test walls, but the adobes can be classified as a sandy loam.[3] Based upon an example calibration curve provided in the technical data sheet for the soil moisture meter, the cells cannot detect any moisture below about 3% in this type of soil. Thus when the meter read 200 x 10,000 ohms, the soil moisture content was about 3%. When the meter read 2.5 x 10,000 ohms, the soil moisture content was about 10%.

[3] In order to determine soil moisture content from resistance meter measurements, the thermistor soil cells must be calibrated soon after installation. Three methods are described in the technical data sheet provided by the manufacturer.

4.0 SUMMARY AND ANALYSIS OF PROTECTIVE COATING EXPERIMENT

Test walls 1 and 2 were used to compare the performance of thirteen different protective coatings in order to determine which, if any, provided an improvement over unamended earthen render without having a significant adverse affect on the physical and mechanical properties of the adobe wall. Treatments included an unamended earthen render and amended earthen renders, and also spray and roll-on treatments which were applied both directly to the adobe and to unamended earthen renders. Treatments incorporated both traditional materials and modern chemicals (Table 3). Each protective coating is described fully in the following sections; manufacturers' information and Material Safety Data Sheets (when available) for the proprietary additives are included in Appendix D.

Each wall measured 65.0' long x 5.0' high x 10" wide, and was set on a foundation of two courses of unamended adobe. Test wall 1 was aligned on an east-west axis and test wall 2 on a north-south axis in order to expose each treatment to the four cardinal directions. The thirteen treatment panels were applied to both sides of each wall, measuring 5.0' x 5.0' x 1", beginning 3"-4" below grade and continuing over the crest of the wall to the opposite side (see Figure 2). Each treatment panel was given a three-character code: the first number represents the test wall number, the letter represents the cardinal direction, and the second number represents the panel number within the wall (e.g., 2S7 is test wall 2, south face, panel 7).

In January of 1986, several structural cracks appeared in test walls 1 and 2. These might have been the result of natural settling or of seismic activity, which was recorded in the Las Cruces area at about that time (Taylor 1986b). The locations and effects of the cracks are discussed in the relevant sections below.

Throughout the course of the project, each protective coating panel was monitored for color change, qualitative erosion, and quantitative erosion (see Section 3.0 for a discussion of monitoring procedures).

Table 3. Protective coatings applied to Fort Selden adobe test walls 1 and 2 (adapted from Taylor 1990).

Test	Panel Numbers	Type	Additive	Composition
1	1N1, 1S1 2E1, 2W1	Render	none	Unamended earthen render
2	1N2, 1S2 (west half) 2E2, 2W2 (south half)	Amended render	El Rey Superior 200 (5% solution)	Methyl methacrylate/acrylate emulsion at 47% solids in water. Same as Rhoplex E-330 with an anti-foaming agent
	1N2, 1S2 (east half) 2E2, 2W2 (north half)	Amended render	El Rey Superior 200 (10 % solution)	
3	1N3, 1S3 (west half) 2E3, 2W3 (south half)	Amended render	Daraweld C (5% solution)	Polyvinyl acetate polymer and vinyl acetate-dibutylmaleate copolymer dispersion at 51% solids in water
	1N3, 1S3 (east half) 2E3, 2W3 (north half)	Amended render	Daraweld C (10% solution)	
4	1N4, 1S4 (west half) 2E4, 2W4 (south half)	Amended render	asphalt emulsion (5% solution)	Petroleum-based product
	1N4, 1S4 (east half) 2E4, 2W4 (north half)	Amended render	asphalt emulsion (10% solution)	
5	1N5, 1S5 (west half) 2E5, 2W5 (south half)	Roll-on	Acryl 60 base coat and Super Quickseal finish coat (on unamended adobe)	Acryl 60: acrylic polymers and modifiers, designed as an additive to Portland cement to improve adhesion and mechanical properties. Super Quickseal: Portland cement, calcium hydroxide, titanium dioxide, and sand coating, a commercial finish coat for masonry and concrete
	1N5, 1S5 (east half) 2E5, 2W5 (north half)	Roll-on	Acryl 60 base coat and Super Quickseal finish coat (on unamended render)	
6	1N6, 1S6 (west half) 2E6, 2W6 (south half)	Spray	K & E Penetrating and Hardening Mineral Sealer (on unamended adobe)	Inorganic mineral salts at 30% solids in water (primarily potassium silicate)
	1N6, 1S6 (east half) 2E6, 2W6 (north half)	Spray	K & E Penetrating and Hardening Mineral Sealer (on unamended render)	
7	1N7, 1S7 (west half) 2E7, 2W7 (south half)	Spray	linseed oil in mineral spirits (on unamended adobe)	1:5 commercial-grade boiled linseed oil in mineral spirits
	1N7, 1S7 (east half) 2E7, 2W7 (north half)	Spray	linseed oil in mineral spirits (on unamended render)	
8	1N8, 1S8 (west half) 2E8, 2W8 (south half)	Roll-on	Thorocoat (on unamended adobe)	A ready-mixed, textured coating composed mainly of calcium carbonate, acrylic emulsion, and titanium dioxide, used for protecting and decorating a variety of exterior and interior surfaces
	1N8, 1S8 (east half) 2E8, 2W8 (north half)	Roll-on	Thorocoat (on unamended render)	
9	1N9, 1S9 (west half) 2E9, 2W9 (south half)	Amended render	agave juice (50% solution)	Extracted from boiled agave leaves, the pulp is pounded and the extract steeped for 2-3 weeks
	1N9, 1S9 (east half) 2E9, 2W9 (north half)	Amended render	agave juice (undiluted)	
10	1N10, 1S10 (west half) 2E10, 2W10 (south half)	Amended render	Soil Seal Concentrate (5% solution)	Latex acrylic balanced with copolymers prepared in emulsion form; consists of 40% polyethoxylated ethanol and 3.55 silicates; 46% solids in water
	1N10, 1S10 (east half) 2E10, 2W10 (north half)	Amended render	Soil Seal Concentrate (10% solution)	
11	1N11, 1S11 (west half) 2E11, 2W11 (south half)	Spray	Silicote (on unamended adobe)	Modified silicone resin spray at 9.9% solids in xylene
	1N11, 1S11 (east half) 2E11, 2W11 (north half)	Spray	Silicote (on unamended render)	
12	1N12, 1S12 (west half) 2E12, 2W12 (south half)	Spray	Seal-Krete (on unamended adobe)	A commercially manufactured acrylic for waterproofing stucco, masonry, cement and adobe
	1N12, 1S12 (east half) 2E12, 2W12 (north half)	Spray	Seal-Krete (on unamended render)	
13	1N13, 1S13 2E13, 2W13	Amended render	straw	4 1-lb. Coffee cans of straw cut into 2-inch lengths were mixed with 1 wheelbarrow of mud

4.1 UNAMENDED EARTH PANELS: 1N1, 1S1, 2E1, 2W1

Unamended earthen render has served as a protective coating since adobe was first used as a building material thousands of years ago. Because of its physical, mechanical, and chemical similarities to adobe, unamended earth is the most compatible protective coating available. However, if unamended earth is exposed to the elements, frequent maintenance is required to keep it in good repair.

Panels 1N1, 1S1, 2E1, and 2W1 were covered with three coats of unamended earthen render, each 1/3" thick.

Color change

The original color of the unamended earthen render was 7.5YR 7/2. No change in color was noted between 1986 and 2000 (Table 4).

Qualitative erosion

The unamended earthen renders deteriorated relatively quickly, especially on the west and north sides of the test walls (Table 5). A perusal of the photographic documentation and commentaries in the status reports (Taylor 1986c; 1987b) reveal that erosion began around exposed shrinkage cracks near the wall tops, and was also heavy at the west and north wall bases probably as a result of capillary rise and backsplash. Through time, erosion progressed steadily and uniformly across the panels as the exposed shrinkage cracks gradually eroded to wide, soft convolutions.

The unamended earthen renders have an erosion index of 3.0, ranking ninth among the thirteen protective coatings and sixth among the seven renders. For unamended earth, the renders performed fairly well and had a working life of up to 1.5 years on exposed walls (north and west) and about 4 years on sheltered walls (south and east).

Table 4. Color of protective coating panels 1S1 and 2E1 over time.

Panel	**1986**	**1987**	**2000**
1S1	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E1	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2

Table 5. Qualitative erosion of protective coating panels 1N1, 1S1, 2E1, and 2W1, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N1	1S1	2E1	2W1	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	4.0	4.5	4.5	3.5	4.1
November 1986	2.5	3.5	3.5	2.0	2.9
November 1987	2.5	3.0	3.0	2.0	2.6
October 1990	2.0	2.5	2.5	1.0	2.0
April 2000	1.0	1.0	2.0	1.0	1.3
Exposure average	2.8	3.3	3.4	2.4	Erosion index = 3.0

Erosion index = mean of the six panel averages

4.2 EL REY SUPERIOR 200 PANELS: 1N2, 1S2, 2E2, 2W2

El Rey Superior Additive 200 is an acrylic dispersion of methyl methacrylate/ethyl acrylate resin sold at 47% solids in water (Hartzler 1996: 5). The product is essentially Rhoplex® E-330 Cement Mortar Modifier, manufactured by Rohm and Haas of Philadelphia, which has been repackaged by the distributor and modified with a defoaming agent.[4] E-330 has been tested and used extensively by the National Park Service since the mid-1970s, most commonly as an additive to earthen repair mortars in the southwestern United States (Hartzler 1996). In 1985, the cost was about $11/gallon.[5]

Panels 1N2, 1S2, 2E2, and 2W2 were covered with three coats of earthen render amended with El Rey Superior 200, each 1/3" thick. Each panel was divided in half (2.5' wide x 5.0' high): on the west and south halves, the render was amended with a 1:10 solution of El Rey Superior 200 in water; on the north and east halves, the render was amended with a 1:5 solution of El Rey Superior 200 in water.[6]

Color change

The El Rey Superior 200 panels were very close to the color of the unamended earthen render (7.5YR 7/2), and no change in color was noted in the first few years (Table 6). No color difference was noted between the weak and strong solutions. After fifteen years of exposure, the south panels became more yellow while the east panels changed color only slightly, if at all. This may be a result of the greater exposure to ultraviolet light experienced by the south-facing panels and subsequent degradation of the acrylic.

Qualitative erosion

The render amended with El Rey Superior Additive 200 deteriorated quite slowly, with the north and west exposures displaying slightly more erosion than the east and south (Table 7). Shrinkage cracks were apparent after four months of exposure, although these were generally minor and very little erosion was noted until two years after application. Most erosion was confined to the upper third of the panel; some increased erosion was noted at the base of the west-facing wall. The weaker 1:10 solution suffered

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[4] Similar or identical products include Primal AC-33 (Horie 1987:111) and Rhoplex MC-76 (Taylor 1990). However, the most recent Material Safety Data Sheet (1999) for Rhoplex E-330 indicates that it is now composed of 46-48 % poly(butyl acrylate/methyl methacrylate), which may mean that the composition of El Rey Superior 200 has also changed. Despite numerous conversations with Rohm and Haas, the author could not determine the date when the composition was changed.

[5] The cost per square meter, x, of a 2.54 cm (1 inch) thick render amended with a 10% solution of any additive, in addition to the cost of the soil and sand, can be computed with the following equation: x = (0.134)(cost of additive/gallon). The cost per square foot = (0.012)(cost of additive/gallon).

[6] Many of the proprietary products are sold at about 50% solids in solution. These products were further diluted for use on the test walls. In the construction narrative (Gossett and Gossett 1985) and in the status reports (Taylor 1986c and 1987b), a 1:10 solution is also described as a 5% solution, and a 1:5 solution is described as a 10% solution. This is not quite correct. A 1:10 solution (11 parts total) of a mixture at about 50% solids would create a 4.5% solution, while a 1:5 solution (6 parts total) would create an 8% solution. It is not certain if the ratios or the percentages are correct. For consistency, only ratios are used in this report.

slightly more erosion, but shrinkage cracks were more common in the stronger 1:5 solution (Taylor 1986c; 1987b). Through time the pattern of erosion was similar to panel 1, and progressed steadily and uniformly across the panels as the exposed shrinkage cracks gradually eroded to soft convolutions. On the wall crests, the 1:10 render has mostly been lost but the 1:5 render is still in good condition.

The renders amended with El Rey Superior 200 have an erosion index of 4.5, ranking first among the thirteen protective coatings and first among the seven renders. Their outstanding performance is not surprising; they have been used at a wide range of earthen sites with consistently good results. Even in low concentrations, the acrylic improves the strength and increases the moisture resistance of soils, regardless of soil type, thus making the soils more resistant to deterioration phenomena like freeze-thaw, salt cycling, abrasion, and high thermal gradient (Hartzler 1996: 46). The acrylic may impart a slight color change and does reduce the water vapor transmission rate, but in a dry environment these effects are usually negligible when weighed against the improvements imparted by the material. On the test walls, the stronger solution performed better than the weaker solution, although both performed well. To reduce expense and improve permeability, the weaker solution might be used on the vertical faces and the stronger solution for the crests of walls.

Table 6. Color of protective coating panels 1S2 and 2E2 over time.

Panel	**1986**	**1987**	**2000**
1S2 (west half)	7.5YR 6/2	7.5YR 6/2	10YR 6.5/3
1S2 (east half)	7.5YR 6/2	7.5YR 6/2	10YR 6.5/3
2E2 (south half)	7.5YR 6/2	7.5YR 6/2	7.5YR 7/2
2E2 (north half)	7.5YR 6/2	7.5YR 6/2	7.5YR 6.5/2

Table 7. Qualitative erosion of protective coating panels 1N2, 1S2, 2E2, and 2W2, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N2	1S2	2E2	2W2	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	5.0	5.0	5.0	5.0	5.0
November 1986	5.0	5.0	5.0	4.5	4.9
November 1987	4.5	5.0	4.5	4.5	4.6
October 1990	4.0	4.0	4.0	4.0	4.0
April 2000	3.0	3.5	3.5	3.0	3.3
Exposure average	4.4	4.6	4.5	4.3	Erosion index = 4.5

Erosion index = mean of the six panel averages

4.3 DARAWELD-C PANELS: 1N3, 1S3, 2E3, 2W3

Daraweld-C® is a polyvinyl acetate polymer and vinyl acetate-dibutylmaleate copolymer dispersion sold at 51% solids in water (Appendix D). Intended as a bonding agent for concrete repair, it has also been used by the National Park Service for adobe preservation since the early 1970s. Its use has diminished due to problems caused by its relative impermeability (Taylor 1987b). In 1985, the cost was about $14/gallon.

Panels 1N3, 1S3, 2E3, and 2W3 were covered with three coats of earthen render amended with Daraweld-C, each 1/3" thick. Each panel was divided in half (2.5' wide x 5.0' high): on the west and south halves, the render was amended with a 1:10 solution of Daraweld-C in water; on the north and east halves, the render was amended with a 1:5 solution of Daraweld-C in water.

Color change

The Daraweld-C panels were identical or quite close in color to the unamended earthen render (7.5YR 7/2) for the first two years of exposure (Table 8). The strong solution was slightly darker than the weak solution. After fifteen years of exposure, the south panels became more yellow, while the east panels were still quite close to their original color. This may be a result of the greater exposure to ultraviolet light experienced by the south-facing panels and subsequent degradation of the vinyl acetate.

Qualitative erosion

The panels amended with Daraweld-C were similar to panels 2 (El Rey Superior 200), 4 (asphalt emulsion) and 10 (Soil Seal Concentrate) in their rate of deterioration. They deteriorated quite slowly, with the north and west exposures displaying slightly more erosion than the east and south (Table 9). Shrinkage cracks were apparent immediately after application, especially in the panels amended with the stronger 1:5 solution. After one year of exposure, sections of the third (outermost) render coat delaminated and fell away, exposing the underlying coat. Minor erosion of the 1:10 solution was noted, but this was not enough to measure with the aluminum rods (Taylor 1986c; 1987b). Some increased erosion was noted at the base of the west-facing wall. Through time the pattern of erosion on the south and east faces was similar to panel 1, progressing steadily and uniformly across the panels as the exposed shrinkage cracks gradually eroded to soft convolutions. However, on north and west faces the render layers had a tendency to detach in sheets, a result of poor adhesion between render coats. On the wall crest, the render is still in place on all exposures but the west despite heavy cracking and detachment.

These renders have an erosion index of 4.3, ranking second among the thirteen protective coatings and second among the seven renders. As with the El Rey, their excellent performance is not surprising; they have been used at a wide range of archaeological sites in the southwestern United States with good short-term results. The dispersion acts as an adhesive, improving the strength and increasing the moisture resistance of soils, thus making them more resistant to deterioration phenomena like freeze-thaw, salt cycling, abrasion, and high thermal gradient. The dispersion does reduce the water vapor transmission rate and yellows over time due to emulsifiers used to create the dispersion (Horie 1987: 94). Over a longer period of time or at a site with greater precipitation or a higher water table, the reduction in water vapor transmission might become a problem. On some faces, the weaker solution performed better than the stronger solution because fewer shrinkage cracks developed, although both solutions performed well. To reduce expense and improve permeability, the weaker solution might be used on the vertical faces and the stronger solution on the crests of walls.

Table 8. Color of protective coating panels 1S3 and 2E3 over time.

Panel	**1986**	**1987**	**2000**
1S3 (west half)	7.5YR 7/2	7.5YR 7/2	10YR 6.5/3
1S3 (east half)	7.5YR 6/2	7.5YR 6/2	10YR 6.5/3
2E3 (south half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E3 (north half)	7.5YR 6/2	7.5YR 6/2	7.5YR 6.5/2

Table 9. Qualitative erosion of protective coating panels 1N3, 1S3, 2E3, and 2W3, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N3	1S3	2E3	2W3	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	5.0	5.0	5.0	5.0	5.0
November 1986	4.5	5.0	5.0	5.0	4.9
November 1987	4.5	5.0	4.5	4.5	4.6
October 1990	3.5	4.5	4.0	3.5	3.9
April 2000	2.0	3.0	3.5	1.5	2.5
Exposure average	4.1	4.6	4.5	4.1	Erosion index = 4.3

Erosion index = mean of the six panel averages

4.4 ASPHALT EMULSION PANELS: 1N4, 1S4, 2E4, 2W4

Asphalt emulsion is composed of microscopic globules of asphalt suspended in water. When mixed with soils, the asphalt coats the surfaces of the clay particles and essentially makes them water repellent. It is sold as a dilute solution at 35% solids in water.

> [Asphalt emulsion] has been used in earthen construction in the near East for thousands of years. In the United States, asphalt emulsion gained widespread use as early as the 1940s and continues to be a popular amendment for stabilized brick used in construction. Asphalt emulsion has been used to some extent as an amendment to mud plaster on unamended mud brick walls. Its use in preservation has been criticized for it makes the plaster much darker than the original material. It also creates a relatively impermeable coating over unamended mud brick walls which inhibits the evaporation of moisture (Taylor 1987b: 10).

In the 1930s, asphalt emulsion was added to earthen render to preserve the walls of the Lincoln County Courthouse in Lincoln, New Mexico. It held up well for at least 25 years with little apparent damage to the underlying adobe walls (Taylor 1986c).

Panels 1N4, 1S4, 2E4, and 2W4 were covered with three coats of earthen render amended with asphalt emulsion, each 1/3" thick. Each panel was divided in half (2.5' wide x 5.0' high): on the west and south halves, the render was amended with a 1:10 solution of asphalt emulsion in water; on the north and east halves, the render was amended with a 1:5 solution of asphalt emulsion in water.

Color change

The asphalt emulsion-amended panels were more yellow and darker than the unamended earth panels (7.5YR 7/2) when initially applied (Table 10). There was no significant color difference between the weaker and stronger solutions. When the surface of the panels was scratched, the color was much darker (10YR 5/4). No color change was noted over time.

Qualitative erosion

The panels amended with asphalt emulsion were remarkably similar to panels 2 (El Rey Superior 200), 3 (Daraweld-C) and 10 (Soil Seal Concentrate) in the kind and rate of deterioration they displayed. They deteriorated slowly, with the west exposure displaying slightly more erosion than the north, south, and east (Table 11). Shrinkage cracks were exposed first in the weaker solution, which also displayed slightly more erosion than the stronger solution (Taylor 1986c; 1987b). After one year of exposure, sections of the third (outermost) render coat delaminated and fell away, exposing the underlying coat. No accelerated erosion was noted at the wall bases. Through time the pattern of erosion was most similar to panel 2, progressing steadily and uniformly across the panels as the exposed shrinkage cracks gradually eroded to soft convolutions. Despite heavy cracking and detachment, the wall crests amended with the stronger solution are still in place.

The asphalt emulsion-amended renders have an erosion index of 4.2, ranking third among the thirteen protective coatings and third among the seven amended renders. Asphalt emulsion has seen widespread and continued use in the adobe construction industry, and this good performance is not surprising. The additive does reduce the water vapor transmission rate of the render, but in a dry environment this effect may be negligible. The chief objection to asphalt emulsion is the much darker color it imparts, and the fact that the surface is lighter than the underlying material, making graffiti a great temptation and an obvious problem. In general, the stronger solution performed better than the weaker solution because fewer shrinkage cracks developed, although both performed well. To reduce expense and improve permeability, the weaker solution might be used on the vertical faces and the stronger solution on the crests of walls.

Table 10. Color of protective coating panels 1S4 and 2E4 over time.

Panel	**1986**	**1987**	**2000**
1S4 (west half)	10YR 6/2	10YR 6/2	10YR 6/2
1S4 (east half)	10YR 6/2	10YR 6/2	10YR 6/2
2E4 (south half)	10YR 6/2	10YR 6/2	10YR 6/2
2E4 (north half)	10YR 6/2	10YR 6/2	10YR 6/2

Table 11. Qualitative erosion of protective coating panels 1N4, 1S4, 2E4, and 2W4, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N4	1S4	2E4	2W4	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	5.0	5.0	5.0	5.0	5.0
November 1986	5.0	5.0	5.0	4.5	4.9
November 1987	4.5	4.0	4.0	4.0	4.1
October 1990	4.0	3.5	4.0	3.5	3.8
April 2000	2.5	2.5	3.0	2.5	2.6
Exposure average	4.3	4.2	4.3	4.1	Erosion index = 4.2

Erosion index = mean of the six panel averages

4.5 ACRYL 60/SUPER QUICKSEAL PANELS: 1N5, 1S5, 2E5, 2W5

Acryl 60® is a solution composed of acrylic polymers and modifiers in water, and was designed for use as an additive for Portland cement to improve adhesion and mechanical properties. It has been used as an additive to earthen render in experiments at Bent's Old Fort National Historic Site, Colorado. Super Quickseal® is a water repellent coating composed of 75-85% Portland cement, 5-15% crystalline quartz silica, 5-10% calcium hydroxide, and 5-10% titanium dioxide. It is used commercially as a finish coat for concrete and masonry, but also has been used to preserve adobe walls in California (Appendix D) (Taylor 1987b). In 1985, the costs of Acryl 60 and Super Quickseal were about $12/gallon.

Panels 1N5, 1S5, 2E5, and 2W5 were each divided in half (2.5' wide x 5.0' high). The east halves of panels 1N5 and 1S5 and the north halves of panels 2E5 and 2W5 were covered with three coats of unamended earthen render. The west halves of panels 1N5 and 1S5 and the south halves of panels 2E5 and 2W5 were pointed with unamended earthen mortar and left exposed. Both halves of all panels were then sprayed with one coat of undiluted Acryl 60 using a hand pump pressure sprayer. After drying, two coats of undiluted Super Quickseal were applied with a latex paint roller.

Color change

The initial color of Super Quickseal was more yellow and darker than the unamended earth panels (7.5YR 7/2) (Table 12). However, it is sold in a variety of premixed colors (Mesa Tan was applied to the test walls) and a custom color presumably could be made for a better match. The color remained stable over the first two years, but after fifteen years of exposure Super Quickseal lightened on the south panels, and became more red and lighter on the east panels. This may be a result of the exposure to ultraviolet light experienced by the panels, and subsequent degradation of the water repellent in the Super Quickseal.

A white film developed on all of the panels where they abutted the asphalt emulsion-amended panels to the west and south. The asphalt amended renders were applied the day after the Super Quickseal was applied, and the white film was probably caused by wetting of the water repellent in Super Quickseal before it had cured.

Qualitative erosion

The panels treated with Acryl 60 and Super Quickseal performed moderately well. A settling crack developed in the west half of panels 1S5 and 1N5 shortly after completion of the walls, which hastened the onset of deterioration. Map cracks developed in the Quickseal wall crests within a year of application, and subsequent erosion was concentrated at the wall tops. The north exposure displayed more erosion than the south, east, and west (Table 13). No accelerated deterioration at the wall bases was noted at any time (Taylor 1986c; 1987b).

The pattern and rate of erosion was most similar to protective coating 8 (Thorocoat), the other roll-on application. The surface of the treatment remained pristine for fifteen years, with no evident erosion. However, cracks in the material allowed water to penetrate to the unamended render and adobe, and as erosion occurred behind the intact surface of the Super Quickseal, portions of the material peeled off.

The Super Quickseal-amended panels have an erosion index of 3.7, ranking sixth among the thirteen protective coatings and second of the two roll-on applications. If cracking could be controlled or eliminated, the additive would perform better. No difference was noted between the additive applied directly to the adobe and the additive applied to the unamended render, probably because both surfaces were first consolidated with Acryl 60 to provide a solid substrate for the Super Quickseal. No information was available on the permeability of the two treatments, but in a wetter climate moisture retention behind the surface of the treatment might become a problem. The texture of the Super Quickseal is that of a modern stucco or a very thick sanded latex paint. It presents a curious contrast to the softer, more gradual and organic erosion patterns of unamended earthen render and adobe.

Table 12. Color of protective coating panels 1S5 and 2E5 over time.

Panel	**1986**	**1987**	**2000**
1S5 (west half)	10YR 6/3 to 10YR 7/2†	10YR 6/3	10YR 7.5/2
1S5 (east half)	10YR 6/3	10YR 6/3	10YR 7.5/2
2E5 (south half)	10YR 7/3	10YR 7/3	7.5YR 8/2
2E5 (north half)	10YR 7/3	10YR 7/3	7.5YR 8/2

†10YR 6/3 at 4 months after application, 10YR 7/2 at 12 months after application.

Table 13. Qualitative erosion of protective coating panels 1N5, 1S5, 2E5, and 2W5, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N5	1S5	2E5	2W5	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	5.0	5.0	5.0	5.0	5.0
November 1986	4.0	4.5	4.0	4.0	4.1
November 1987	3.5	3.5	3.0	3.5	3.4
October 1990	3.0	3.5	3.0	3.0	3.1
April 2000	1.0	1.0	3.0	2.0	1.8
Exposure average	3.6	3.8	3.8	3.8	Erosion index = 3.7

Erosion index = mean of the six panel averages

4.6 K & E Mineral Sealer panels: 1N6, 1S6, 2E6, 2W6

K & E Super Hard Penetrating Mineral Sealer is a “clear, non-yellowing, odorless, water-based, non-flammable formulation of minerals” designed to penetrate, seal, and harden masonry surfaces, and is sold at 30% solids in water (Appendix D). It is composed primarily of potassium silicate (Bleick 2000, personal communication). The product was sprayed on the test walls at Bent’s Old Fort National Historic Site and displayed little erosion after three years of exposure (Taylor 1987b: 20). In 1985, the cost was about $10/gallon.

Panels 1N6, 1S6, 2E6, and 2W6 were each divided in half (2.5’ wide x 5.0’ high). The east halves of panels 1N6 and 1S6 and the north halves of panels 2E6 and 2W6 were covered with three coats of unamended earthen render. The west halves of panels 1N6 and 1S6 and the south halves of panels 2E6 and 2W6 were pointed with unamended earthen mortar and left exposed. Both halves of all panels were then sprayed with one coat of undiluted K & E Super Hard Penetrating Mineral Sealer.

Color change

The panels sprayed with K & E were quite close or identical in color to the unamended earth panels (7.5YR 7/2) immediately after application (Table 14). The south panels became less yellow after the first year, and all panels were identical in color to the unamended earth after two and fifteen years of exposure.

Qualitative erosion

The panels treated with K & E Super Hard Penetrating Mineral Sealer performed quite poorly, in fact worse than the unamended render on panel 1. The product began to exfoliate from the wall tops within 4 months of application. The west, north, and south exposures displayed much more erosion than the east (Table 15). No accelerated deterioration at the wall bases was noted (Taylor 1986c; 1987b). A settling crack developed in the center of panels 1S6 and 1N6 shortly after completion of the walls, but this was not associated with any increased deterioration.

The pattern and rate of erosion was most similar to treatments 7 (linseed oil) and 12 (Seal-Krete), two other spray applications. Pits developed in the sprayed render after 8 months of exposure, during the rainy season. These pits quickly became larger and eroded to the depth of the adobe wall while the surrounding render remained in excellent condition and displayed little or no erosion except at the wall caps, where erosion was more uniform but rapid. The deterioration of the sprayed adobes was less visually dramatic but also rapid.

The K & E-amended panels have an erosion index of 2.8, ranking twelfth among the thirteen protective coatings and third among the four spray applications. Depth of penetration was quite poor, about 1 mm; a depth of penetration of 3 to 5 cm is normally recommended for consolidants, somewhat less for water repellents. Because the product created a relatively hard, impermeable, and possibly water-repellent surface crust on the render, erosion was concentrated in areas where the crust was weak or had failed, creating an unusual deterioration pattern which most resembled Swiss cheese.

Table 14. Color of protective coating panels 1S6 and 2E6 over time.

Panel	**1986**	**1987**	**2000**
1S6 (west half)	10YR 7/2	7.5YR 7/2	7.5YR 7/2
1S6 (east half)	10YR 7/2	7.5YR 7/2	7.5YR 7/2
2E6 (south half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E6 (north half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2

Table 15. Qualitative erosion of protective coating panels 1N6, 1S6, 2E6, and 2W6, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N6	1S6	2E6	2W6	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	4.0	3.5	4.5	3.5	3.9
November 1986	2.0	2.5	3.5	2.0	2.5
November 1987	2.0	2.5	3.0	1.5	2.3
October 1990	2.0	2.5	3.0	1.5	2.3
April 2000	1.0	1.0	1.0	1.0	1.0
Exposure average	2.7	2.8	3.3	2.4	Erosion index = 2.8

Erosion index = mean of the six panel averages

4.7 Linseed oil panels: 1N7, 1S7, 2E7, 2W7

Linseed oil has been used to a limited extent to preserve earthen renders by both spray and brush application; it has also been used to consolidate earthen floors. At Bent's Old Fort National Historic Site, it was used on test walls in a 1:2 solution in mineral spirits which showed very little erosion after three years of exposure (Taylor 1987b: 22). In 1985, the cost of commercial grade linseed oil was about $10/gallon.

Panels 1N7, 1S7, 2E7, and 2W7 were each divided in half (2.5' wide x 5.0' high). The east halves of panels 1N7 and 1S7 and the north halves of panels 2E7 and 2W7 were covered with three coats of unamended earthen render. The west halves of panels 1N7 and 1S7 and the south halves of panels 2E7 and 2W7 were pointed with unamended earthen mortar and left exposed. Both halves of all panels were then sprayed with two coats of commercial grade, boiled linseed oil diluted 1:5 with mineral spirits.

Color change

The panels sprayed with linseed oil were identical in color to the unamended earth panels (7.5YR 7/2) and displayed no color change after fifteen years of exposure (Table 16).

Qualitative erosion

The panels treated with linseed oil performed quite poorly, and were in fact the worst of all of the protective coating treatments. The product began to flake on and just below the wall tops within 4 months of application. The west and north exposures displayed much more erosion than the south and east (Table 17). Accelerated deterioration at the base of the south wall was noted, probably from backsplash or capillary rise of surface water. On the other three exposures, overall erosion was too rapid for any accelerated erosion to become obvious. A settling crack developed in the center of panels 1S7 and 1N7 shortly after completion of the walls, but this was not associated with any increased deterioration (Taylor 1986c; 1987b).

The pattern and rate of erosion was most similar to panels 6 (K & E Mineral Sealer) and 12 (Seal-Krete), two other spray applications. Pits and crevices developed along shrinkage cracks in the sprayed render after 8 months of exposure, during the rainy season. These pits quickly became larger and eroded to the depth of the adobe wall in some areas by 12 months, while the surrounding render suffered heavy erosion but at a more uniform rate. The deterioration of the sprayed adobes was less visually dramatic but also rapid, and rivulets or runoff channels formed in the adobe bricks. After 24 months of exposure, nothing remained of the wall crest on test wall 1.

The linseed oil-amended renders have an erosion index of 2.7, ranking last among the thirteen protective coatings and fourth among the four spray applications. Depth of penetration is unknown but was probably quite poor, 1 mm or less; a depth of penetration of 3 to 5 cm is normally recommended for consolidants, somewhat less for water repellents. Because the product created a relatively impermeable and possibly water-repellent surface crust on the render, erosion was concentrated in areas where the crust was weak or had failed, creating an unusual deterioration pattern which resulted in deep crevices, pits and channels.

Table 16. Color of protective coating panels 1S7 and 2E7 over time.

Panel	1986	1987	2000
1S7 (west half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
1S7 (east half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E7 (south half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E7 (north half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2

Table 17. Qualitative erosion of protective coating panels 1N7, 1S7, 2E7, and 2W7, 1985-2000.

Date	Qualitative Erosion				Panel average
	1N7	1S7	2E7	2W7	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	4.0	5.0	4.0	2.5	3.9
November 1986	2.0	2.5	3.0	1.5	2.3
November 1987	2.0	2.5	2.5	1.5	2.1
October 1990	2.0	2.5	2.5	1.5	2.1
April 2000	1.0	1.0	1.0	1.0	1.0
Exposure average	2.7	3.1	3.0	2.2	Erosion index = 2.7

Erosion index = mean of the six panel averages

4.8 THOROCOAT PANELS: 1N8, 1S8, 2E8, 2W8

Thorocoat® is a "100% acrylic, textured coating specifically designed to protect and decorate a wide variety of exterior and interior surfaces. It is heavy bodied to fill pores in concrete block or create a pleasing texture on smooth surfaces. Thorocoat contains a new emulsion polymer with a uniquely combined and balanced monomer composition." The Material Safety Data Sheet reports that the major ingredients are calcium carbonate (20-25%), acrylic polymer in aqueous emulsion (15-25%), and titanium dioxide (10-15%) (Appendix D). Thorocoat also possesses good resistance to abrasion, freeze-thaw cycling, and fungal attack (from product literature, see Appendix D). It is not known if Thorocoat has previously been used on adobe walls, but was tested at the manufacturer's suggestion (Taylor 1987b: 28). In 1985, the cost of Thorocoat was about $10/gallon.

Panels 1N8, 1S8, 2E8, and 2W8 were each divided in half (2.5' wide x 5.0' high). The east halves of panels 1N8 and 1S8 and the north halves of panels 2E8 and 2W8 were covered with three coats of unamended earthen render. The west halves of panels 1N8 and 1S8 and the south halves of panels 2E8 and 2W8 were pointed with unamended earthen mortar and left exposed. Thorocoat was then applied to both halves of all panels using a latex paint roller. A second coat was applied just before the first coat had dried.

Color change

Thorocoat was more yellow than the unamended earth panels (7.5YR 7/2) (Table 18). However, it is sold in a variety of premixed colors (Mesa Tan was applied to the test walls) and a custom color presumably could be made for a better match. The color remained stable over the course of the project, with only a slight fading on the east panels after fifteen years.

Qualitative erosion

The panels treated with Thorocoat performed moderately well. Settling cracks developed in the center of panels 1S8 and 1N8 and in the north half of panel 2E8 shortly after completion of the walls, which hastened deterioration. This initial cracking may have led to the development of other cracks which appeared after about 12 months of exposure (Taylor 1986c; 1987b). The east and west exposures displayed more erosion than the north and south (Table 19). This is one of two instances where an east face displayed the worst erosion in a set of panels, and is probably a result of the large settlement crack. No accelerated deterioration at the wall bases was noted at any time.

The pattern and rate of erosion was most similar to panel 5 (Acryl 60/Super Quickseal), the other roll-on treatment. The surface of the treatment remained pristine for fifteen years, with no evident erosion. However, cracks in the material allowed water to penetrate to the unamended render and adobe, and as erosion occurred behind the intact surface of the Thorocoat, portions of the material blistered and peeled off.

The Thorocoat-protected panels have an erosion index of 3.8, tying for fourth among the thirteen protective coatings and ranking first of the two roll-on treatments. If cracking could be controlled or eliminated, the product would perform better. The product applied directly to the adobe did not perform as well as the product applied to the unamended render, probably because the rendered surface provided a more uniform and less friable substrate for the Thorocoat. No information was available on the permeability of Thorocoat, but moisture retention behind the surface probably led to the blistering of the treatment and the subsequent erosion of the underlying render and adobe. The texture of the Thorocoat is that of a modern stucco or a very thick sanded latex paint, and it tended to develop bubbles or large blisters. Its surface finish remains pristine even as it peels from the wall, and presents a curious contrast to the softer, more gradual and organic erosion patterns of the unamended render and adobe.

Table 18. Color of protective coating panels 1S8 and 2E8 over time.

Panel	**1986**	**1987**	**2000**
1S8 (west half)	10YR 7/4	10YR 7/4	10YR 7/4
1S8 (east half)	10YR 7/4	10YR 7/4	10YR 7/4
2E8 (south half)	10YR 7/4	10YR 7/4	10YR 7/3
2E8 (north half)	10YR 7/4	10YR 7/4	10YR 7/3

Table 19. Qualitative erosion of protective coating panels 1N8, 1S8, 2E8, and 2W8, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N8	1S8	2E8	2W8	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	5.0	5.0	5.0	5.0	5.0
November 1986	5.0	5.0	3.0	5.0	4.5
November 1987	3.5	4.0	2.0	4.0	3.4
October 1990	3.5	4.0	2.0	3.0	3.1
April 2000	2.5	2.5	1.5	1.0	1.9
Exposure average	4.1	4.3	3.1	3.8	Erosion index = 3.8

Erosion index = mean of the six panel averages

4.9 AGAVE JUICE PANELS: 1N9, 1S9, 2E9, 2W9

Agave juice was produced by boiling the leaves of an agave plant (scientific name not known) collected on the Monument grounds, and then pounding the pulp. This extract was steeped in water for two to three weeks before use. Juice and mucilage from a variety of plants, particularly cacti, have long been used by traditional desert cultures as earthen render additives (Taylor 1987b: 12).

Panels 1N9, 1S9, 2E9, and 2W9 were covered with two coats of unamended earthen render, each 1/3” thick. Each panel was then divided in half (2.5’ wide x 5.0’ high): on the west and south halves, the third render coat was amended with a 1:1 solution of agave juice in water; on the north and east halves, the third render coat was amended with an undiluted solution of agave juice. This third coat was not applied until March of 1986, four months after the other protective coatings had been applied.

Color change

The panels amended with agave juice were identical in color to the unamended earth panels (7.5YR 7/2) and displayed no color change after fifteen years of exposure (Table 20).

Qualitative erosion

The panels treated with agave juice performed quite poorly, and were in fact the worst of all of the amended render treatments. The renders began to display uniform erosion almost immediately after application. Over time, the west and east exposures displayed much more erosion than the north and south (Table 21). Accelerated deterioration was noted at the bases of all walls (Taylor 1986c; 1987b).

The pattern and rate of erosion was most similar to panel 1 (unamended earth). Erosion began around exposed shrinkage cracks near the wall tops and was also heavy at the west and north wall bases, probably as a result of capillary rise and backsplash. Through time, erosion progressed steadily and uniformly across the panels as the exposed shrinkage cracks gradually eroded to wide, soft convolutions. There was no difference in the kind or rate of erosion between the stronger and weaker solutions of agave juice.

The agave juice-amended renders have an erosion index of 2.9, tied for tenth among the thirteen protective coatings, ranking last among the seven renders, and performing worse than the unamended earth on panel 1. This poor performance may be inherent to the agave cactus juice, which may have little or no water repellent, consolidative or adhesive properties, or the way in which it was prepared for use. At the time the test wall project began, the evidence in favor of cacti additives was largely empiric and anecdotal. Since then, several studies have proven that such additives can increase erosion resistance (Neumann et al. 1987, Beas 1991). Further research and experimentation with agave and other cactus juices and mucilages would most likely yield better results.

Table 20. Color of protective coating panels 1S9 and 2E9 over time.

Panel	**1986**	**1987**	**2000**
1S9 (west half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
1S9 (east half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E9 (south half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E9 (north half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2

Table 21. Qualitative erosion of protective coating panels 1N9, 1S9, 2E9, and 2W9, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N9	1S9	2E9	2W9	
March 1986	5.0	5.0	5.0	5.0	5.0
November 1986	3.5	3.5	2.5	3.0	3.1
November 1987	3.5	3.0	2.5	2.5	2.9
October 1990	2.5	2.5	2.5	1.0	2.1
April 2000	1.0	1.0	2.0	1.0	1.3
Exposure average	3.1	3.0	2.9	2.5	Erosion index = 2.9

Erosion index = mean of the five panel averages

4.10 SOIL SEAL PANELS: 1N10, 1S10, 2E10, 2W10

Soil Seal Concentrate is a latex acrylic emulsion composed of a copolymer of methacrylates and acrylates (40%), polyethoxylated ethanol (1%), and silicates (3.5%), sold at 46% solids in water. It is used commercially for soil surface erosion control and as a "tackifier" in hydroseeding and mulching applications. Also, it was used as a stabilizer in adobe and earthen mortar at Pecos National Historical Park in the 1970s and in test wall experiments at Bent's Old Fort National Historic Site [Ulis 1983; product literature (see Appendix D); and Taylor 1987b: 6]. In 1985, the cost was $9/gallon.

Panels 1N10, 1S10, 2E10, and 2W10 were covered with three coats of earthen render amended with Soil Seal Concentrate, each 1/3" thick. Each panel was divided in half (2.5' wide x 5.0' high): on the west and south halves, the render was amended with a 1:10 solution of Soil Seal Concentrate in water; on the north and east halves, the render was amended with a 1:5 solution of Soil Seal Concentrate in water.

Of all the additives, only Soil Seal was difficult to apply: it "puffs like pizza dough, is very sticky and adheres to the trowel" (Gossett and Gossett 1985: 12).

Color change

The initial color of the renders amended with Soil Seal Concentrate was slightly darker than the panels of unamended earth (7.5YR 7/2) (Table 22). After fifteen years of exposure, the panels lightened in color to match the unamended panels. However, some darker, yellower streaks were observed in the south-facing amended panels.

Qualitative erosion

The panels amended with Soil Seal Concentrate were similar to panels 2 (El Rey Superior 200), 3 (Daraweld-C) and 4 (asphalt emulsion), all amended renders, in the kind and rate of deterioration they displayed. The Soil Seal panels deteriorated slowly, with the west exposure displaying more erosion than the north, south, and east (Table 23). Numerous shrinkage cracks developed in the 1:5 solutions, and after 12 months of exposure cracks developed between the vertical wall faces and the wall crests (Taylor 1986c; 1987b). Through time the cracks at the wall crests allowed water to penetrate, causing further separation and erosion of the protective coatings and erosion of the adobe. Some accelerated erosion was noted at all of the wall bases.

The pattern of erosion was most similar to panel 2, progressing steadily and uniformly across the panels as the exposed shrinkage cracks gradually eroded to soft convolutions. The wall crests on test wall 1 were lost after about three years of exposure, but the crests on test wall 2 lasted several years longer.

The Soil Seal-amended renders have an erosion index of 3.8, tied for fourth among the thirteen protective coatings and ranking fourth among the seven amended renders. This good performance is not surprising, as Soil Seal Concentrate is similar in composition to El Rey Superior 200. The additive may reduce the water vapor transmission rate of the render, but in a dry environment this effect may be negligible. The chief flaws of the product were the development of shrinkage cracks immediately after application, which hastened the onset and severity of erosion at the wall tops, and the difficulty in applying it. In general, the weaker solution performed better than the stronger solution because fewer shrinkage cracks developed, although both performed moderately well.

Table 22. Color of protective coating panels 1S10 and 2E10 over time.

Panel	**1986**	**1987**	**2000**
1S10 (west half)	7.5YR 6/2	-	7.5YR 7/2 to 10YR 6.5/3†
1S10 (east half)	7.5YR 6/2	-	7.5YR 7/2 to 10YR 6.5/3†
2E10 (south half)	7.5YR 6/2	-	7.5YR 7/2
2E10 (north half)	7.5YR 6/2	-	7.5YR 7/2

†Surface is streaked, with dark and light areas.

Table 23. Qualitative erosion of protective coating panels 1N10, 1S10, 2E10, and 2W10, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N10	1S10	2E10	2W10	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	5.0	5.0	5.0	4.0	4.8
November 1986	4.0	4.5	4.0	4.0	4.1
November 1987	3.5	3.5	3.5	4.0	3.6
October 1990	3.0	3.5	3.5	2.5	3.1
April 2000	2.5	3.0	2.5	1.0	2.3
Exposure average	3.8	4.1	3.9	3.4	Erosion index = 3.8

Erosion index = mean of the six panel averages

4.11 SILICOTE PANELS: 1N11, 1S11, 2E11, 2W11

Silicote is a modified silicone resin sold at 9.9% solids in xylenes; it is manufactured by Wellborn Paint Manufacturing Co., PO Box 25645, Albuquerque, NM 87125. It is not known if it has been used for adobe preservation (Taylor 1987b: 24). In 1985, the cost was about $18/gallon.

Panels 1N11, 1S11, 2E11, and 2W11 were each divided in half (2.5' wide x 5.0' high). The east halves of panels 1N11 and 1S11 and the north halves of panels 2E11 and 2W11 were covered with three coats of unamended earthen render. The west halves of panels 1N11 and 1S11 and the south halves of panels 2E11 and 2W11 were pointed with unamended earthen mortar and left exposed. Both halves of all panels were then sprayed with two coats of undiluted Silicote using a hand pump pressure sprayer.

Color change

The panels sprayed with Silicote were identical in color to the unamended earth panels (7.5YR 7/2) and displayed no color change after fifteen years of exposure (Table 24).

Qualitative erosion

The panels treated with Silicote performed moderately well. The product began to flake from the wall tops, especially from the unrendered adobe block, within 4 months of application. Curiously, the east exposure displayed the earliest and most severe erosion, while the west, north, and south exposures displayed much less (Table 25). No accelerated deterioration at the wall bases was noted (Taylor 1986c; 1987b). A settling crack developed in the center of panel 1N11 shortly after completion of the wall, but this was not associated with much accelerated deterioration.

The pattern and rate of erosion varied considerably from exposure to exposure, more so than any other treatment. However, Silicote was most similar to additives 6 (K & E Mineral Sealer), 7 (linseed oil) and 12 (Seal-Krete), the three other spray applications. On the south face, pits developed in the sprayed render after 18 months of exposure. These pits quickly became larger and eroded to the depth of the adobe wall while the surrounding render remained in excellent condition and displayed little or no erosion except at the wall crests, where erosion was more uniform but rapid. On the north and west faces, the vertical faces of the rendered panels remained in excellent condition fifteen years after application. However, cracks between the vertical faces and the crests led to early separation and deterioration of the crest. The deterioration of the sprayed adobes was less visually dramatic but more rapid, and rivulets formed on some of the panels as they did in the linseed oil panels. On the anomalous east panel, the erosion of the rendered panel most resembled that of unamended adobe. It is possible that no Silicote or only one coat was sprayed on this panel. Otherwise, the inconsistent erosion patterns from face to face may be related to application technique and environmental conditions.

The Silicote-amended renders have an erosion index of 3.2, ranking seventh among the thirteen protective coatings and first among the four spray applications despite the poor performance of the east panel. Depth of penetration was poor, about 3 mm; a depth of penetration of 3 to 5 cm is normally recommended for consolidants, somewhat less for water repellents. The product created a relatively hard, impermeable, and possibly water-repellent surface crust on the render and erosion was concentrated in areas where the crust was weak or had cracked and failed, creating an unusual pitted deterioration pattern. However, this pattern was relatively rare and Silicote performed rather well for a spray application.

Table 24. Color of protective coating panels 1S11 and 2E11 over time.

Panel	**1986**	**1987**	**2000**
1S11 (west half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
1S11 (east half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E11 (south half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E11 (north half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2

Table 25. Qualitative erosion of protective coating panels 1N11, 1S11, 2E11, and 2W11, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N11	1S11	2E11	2W11	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	5.0	4.0	4.0	5.0	4.5
November 1986	4.0	3.5	2.0	3.5	3.3
November 1987	3.5	3.0	2.0	2.5	2.8
October 1990	3.5	2.5	3.0	1.0	2.5
April 2000	1.0	1.0	1.0	1.0	1.0
Exposure average	3.7	3.2	2.8	3.0	Erosion index = 3.2

Erosion index = mean of the six panel averages

4.12 SEAL-KRETE PANELS: 1N12, 1S12, 2E12, 2W12

Seal-Krete Sealer is an acrylic-based water repellent used to treat stucco, masonry, cement, and adobe (Appendix D). It is not known if it has been used successfully to preserve adobe or earthen render.

Panels 1N12, 1S12, 2E12, and 2W12 were each divided in half (2.5' wide x 5.0' high). The east halves of panels 1N12 and 1S12 and the north halves of panels 2E12 and 2W12 were covered with three coats of unamended earthen render. The west halves of panels 1N12 and 1S12 and the south halves of panels 2E12 and 2W12 were pointed with unamended earthen mortar and left exposed. Both halves of all panels were then sprayed with two coats of undiluted Seal-Krete Sealer using a hand pump pressure sprayer.

Color change

The panels sprayed with Seal-Krete were identical in color to the unamended earth panels (7.5YR 7/2) and displayed no color change after fifteen years of exposure (Table 26).

Qualitative erosion

The panels treated with Seal-Krete performed poorly. The product began to flake on and just below the wall tops within 4 months of application (Taylor 1986c; 1987b). The west and north exposures displayed more erosion than the south and east (Table 27). Accelerated deterioration at the base of the north and south walls was noted.

The pattern and rate of erosion was most similar to panels 6 (K & E Mineral Sealer) and 7 (linseed oil), two other spray applications. Pits and crevices developed along shrinkage cracks in the sprayed render after 8 months of exposure, during the rainy season. On several panels, these pits quickly became larger and eroded to the depth of the adobe wall in some areas by 12 months, while the surrounding render suffered heavy erosion but at a more uniform rate. The deterioration of the sprayed adobes was less visually dramatic but also rapid. After 24 months of exposure, very little remained of the crests on test walls 1 and 2.

The Seal-Krete-amended panels have an erosion index of 2.9, tying for tenth among the thirteen protective coatings and ranking second among the four spray applications. Depth of penetration is unknown but was probably quite poor, 1 mm or less; a depth of penetration of 3 to 5 cm is normally recommended for consolidants, somewhat less for water repellents. Because the product created a relatively hard, impermeable, and possibly water-repellent surface crust on the render, erosion was concentrated in areas where the crust was weak or had failed, creating an unusual deterioration pattern which resulted in deep crevices, pits and channels.

Table 26. Color of protective coating panels 1S12 and 2E12 over time.

Panel	**1986**	**1987**	**2000**
1S12 (west half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
1S12 (east half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E12 (south half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E12 (north half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2

Table 27. Qualitative erosion of protective coating panels 1N12, 1S12, 2E12, and 2W12, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N12	1S12	2E12	2W12	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	4.0	4.0	5.0	3.5	4.1
November 1986	2.5	3.0	3.5	1.0	2.5
November 1987	2.5	3.0	3.5	1.0	2.5
October 1990	2.5	2.5	3.0	1.0	2.3
April 2000	1.0	1.0	1.0	1.0	1.0
Exposure average	2.9	3.1	3.5	2.1	Erosion index = 2.9

Erosion index = mean of the six panel averages

4.13 EARTH WITH STRAW PANELS: 1N13, 1S13, 2E13, 2W13

Straw has been used universally as an earthen render additive.

> It has been claimed that it acts as a binder which reduces cracking on wall surfaces and thus extends the life of the plaster application. Its use is criticized by some preservationists who claim that it encourages penetration of moisture, reduces compressive strength when used in adobe brick manufacture, and that insects follow the straw as a food source into the wall (Taylor 1987b: 14).

Panels 1N13, 1S13, 2E13, and 2W13 were covered with one coat of unamended earthen render, 1/3" thick. The remaining two coats were amended with oat straw, cut into 1" lengths; each coat was 1/3" thick. The ratio was 4 1-lb. coffee cans of straw per wheelbarrow of mud mix (approximately 3 cubic feet).

Color change

The panels amended with straw were identical in color to the unamended earth panels (7.5YR 7/2) and displayed no color change after fifteen years of exposure (Table 28).

Qualitative erosion

The straw-amended earthen renders deteriorated relatively quickly, especially on the west and east sides of the test walls (Table 29). Erosion began around exposed shrinkage cracks near the wall tops, and was also heavy at the north wall base probably as a result of capillary rise and backsplash (Taylor 1986c; 1987b). Through time, erosion progressed steadily and uniformly across the panels as the exposed shrinkage cracks gradually eroded to wide, soft convolutions. Insects did prove to be a problem: termites created tunnels through the render on the north panel, accelerating its erosion (Taylor 1990: 385).

The straw-amended earthen renders have an erosion index of 3.1, ranking eighth among the thirteen protective coatings and fifth among the seven renders. For earth, the renders performed fairly well and had a working life of up to 2 years on exposed walls (north and west) and about 4 years on one sheltered wall (south). The relatively sheltered east wall showed surprisingly rapid deterioration; the causes of this are unknown. In sum, the straw-amended panels were quite similar to the unamended earthen panels. Straw only reduces shrinkage cracking and possibly improves tensile strength. It does not improve erosion or abrasion resistance, which were the primary deterioration mechanisms affecting the test walls.

Table 28. Color of protective coating panels 1S13 and 2E13 over time.

Panel	**1986**	**1987**	**2000**
1S13 (west half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
1S13 (east half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E13 (south half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2
2E13 (north half)	7.5YR 7/2	7.5YR 7/2	7.5YR 7/2

Table 29. Qualitative erosion of protective coating panels 1N13, 1S13, 2E13, and 2W13, 1985-2000.

Date	**Qualitative Erosion**				**Panel average**
	1N13	1S13	2E13	2W13	
November 1985	5.0	5.0	5.0	5.0	5.0
March 1986	4.5	4.5	4.5	4.0	4.4
November 1986	3.5	3.5	3.0	2.5	3.1
November 1987	3.0	3.5	2.5	2.5	2.9
October 1990	3.0	3.0	2.5	1.0	2.4
April 2000	1.0	1.0	1.0	1.0	1.0
Exposure average	3.3	3.4	3.1	2.7	Erosion index = 3.1

Erosion index = mean of the six panel averages

4.14 CONCLUSIONS AND RECOMMENDATIONS

Test walls 1 and 2 of the Adobe Test Wall Project – Phase I have been exposed to the extreme climate of southern New Mexico for fifteen years. The data collected during that time provides definitive answers about the qualitative weathering characteristics of the thirteen protective coatings tested on those walls, including color matching and stability, erosion resistance, material compatibility, texture, and weathering patterns. Information on quantitative erosion resistance was also derived from aluminum monitoring rods which were built into the walls.

Color matching and stability

Six of the twelve protective coatings were identical or very similar in color to the unamended earthen render on panel 1, and were stable over time. These included panel 7 (linseed oil), panel 9 (agave juice), panel 11 (Silicote), panel 12 (Seal-Krete), and panel 13 (straw).

The colors of three of the protective coatings were initially identical or similar to panel 1, but changed over time; these were panel 2 (El Rey Superior 200), panel 3 (Daraweld-C), and panel 5 (Super Quickseal), all of which became lighter or slightly more yellow over time. As well, the south faces of these panels discolored differently than the east faces. These discolorations are probably a result of the greater exposure to ultraviolet light experienced by the south-facing panels and subsequent degradation of the additives.

Two protective coatings initially darkened the render but lightened to match the unamended earth after one or two years. These were panel 6 (K & E Mineral Sealer) and panel 10 (Soil Seal Concentrate).

Three panels were poor color matches, but two of these, panel 5 (Super Quickseal) and panel 8 (Thorocoat), can be purchased in a range of premixed colors. Presumably, a custom color could be blended to better match the unamended earthen materials. The third poor color match, panel 4 (asphalt emulsion), was much darker than the unamended earth although it did remain stable over time. Perhaps its greatest drawback is that when the surface is scratched, the color beneath is much darker and more yellow, making this amended render vulnerable to graffiti.

To improve color matching, stable mineral-based pigments can be added to amended earthen render mixes. However, adequate mixing and mixing time are critical to ensure the even distribution of the pigment throughout the render, and results are often inconsistent because the soil was damp or was not mixed sufficiently. The addition of pigments also adds expense in terms of time and materials.

Erosion resistance

The roll-on applications provided the best absolute erosion resistance; these included panel 5 (Acryl 60/Super Quickseal) and panel 8 (Thorocoat) (Table 30). After fifteen years of weathering, intact surfaces show no signs of erosion. However, the roll-on applications failed early when water penetrated shrinkage or settling cracks, eroded the underlying unamended render or adobe and causing the product to peel from the substrate. The acrylic, vinyl acetate, and asphalt amended renders, though not as erosion-resistant, displayed more gradual and uniform deterioration and thus had the longest useful life; these included panels 2 (El Rey Superior 200), 3 (Daraweld-C), 4 (asphalt emulsion), and 10 (Soil Seal Concentrate). The traditionally-amended renders (panel 9, agave juice, and panel 13, straw) showed no improvement over the unamended render on panel 1. The spray applications displayed very little erosion resistance once the surface crust was breached. Because the sprays had such poor depth of penetration (about 1-3 mm), these crusts were breached quickly and three of the four sprays did not extend the useful life of the render beyond that of the unamended earth; these included panels 6 (K & E Mineral Sealer), 7 (linseed oil), and 12 (Seal-Krete). Panel 11 (Silicote) displayed just slightly more erosion resistance than the unamended and straw-amended panels. In summary, the roll-on applications displayed the best absolute erosion resistance, but the acrylic, vinyl acetate, and asphalt amended renders displayed the best overall erosion resistance and provided the best protection for the adobe walls.

Table 30. Summary of average rates of erosion, erosion indices, and overall ranking of panels on Fort Selden test walls 1 and 2.

Panel	**Additive**	**Application**	**Average erosion**				**Erosion index**	**Ranking**
			North	South	East	West		
1	unamended earth	render	2.8	3.3	3.4	2.4	3.0	9
2	El Rey 200	render	4.4	4.6	4.5	4.3	4.5	1
3	Daraweld-C	render	4.1	4.6	4.5	4.1	4.3	2
4	asphalt emulsion	render	4.3	4.2	4.3	4.1	4.2	3
5	Acryl 60/Super Quickseal	roll-on	3.6	3.8	3.8	3.8	3.7	6
6	K & E	spray	2.7	2.8	3.3	2.4	2.8	12
7	linseed oil	spray	2.7	3.1	3.0	2.2	2.7	13
8	Thorocoat	roll-on	4.1	4.3	3.1	3.8	3.8	4 (tie)
9	agave juice	render	3.1	3.0	2.9	2.5	2.9	10 (tie)
10	Soil Seal Concentrate	render	3.8	4.1	3.9	3.4	3.8	4 (tie)
11	Silicote	spray	3.7	3.2	2.8	3.0	3.2	7
12	Seal-Krete Sealer	spray	2.9	3.1	3.5	2.1	2.9	10 (tie)
13	straw	render	3.3	3.4	3.1	2.7	3.1	8
Total average erosion			3.5	3.7	3.5	3.1		

Material compatibility

No laboratory tests were conducted to measure the physical, mechanical, or chemical properties of the protective coatings and their effects on the underlying adobe. However, general assumptions about material compatibility can be made based upon the known properties and past performance of a number of the additives. The non-chemically amended renders were the most similar to the adobe walls and thus the most compatible; these included panels 1 (unamended earth) and 13 (straw).

The roll-on applications were probably the most dissimilar from the adobe; these included panels 5 (Acryl 60/Super Quickseal) and 8 (Thorocoat). They were designed to protect the substrate to which they were applied by encapsulating it in an entirely new material, not by strengthening or altering the existing material. In fact, the adobe and earthen render on panel 5 had to be consolidated first with an acrylic in order to provide a sound substrate for the encapsulating Super Quickseal. The roll-on applications formed thick, hard, and relatively impermeable barriers on the surface of the adobe or unamended render.

The spray applications (oils, acrylics, silicones, silicates, and alkali salts) were designed to make the surface to which they were applied water-repellent, and in some cases to strengthen the surface as well. The concept is valid but most of the products were not designed for use on adobe or earthen render, and because they achieved such poor depth of penetration, only water-repellent crusts were formed. Differences in coefficients of expansion, upon wetting, between the water repellent crust and the absorbent, untreated earth probably contributed to the initial failure of the crust (Coffman et al. 1990: 253). Then erosion often began in any cracks or weaknesses in the crusts; once initial erosion occurred, subsequent erosion was relatively rapid (more rapid than in the unamended render of panel 1) as water was channeled from the less permeable amended crust into the softer and more permeable unamended earth. This process is similar to the geomorphological phenomenon of differential erosion, by which gullies and canyons are formed; these then concentrate water flow, further increasing erosion. Spray applications included panels 6 (K & E Mineral Sealer), 7 (linseed oil), 11 (Silicote), and 12 (Seal-Krete). These materials might have worked better if they were mixed with earthen render prior to application; however, the water-repellent render might not have adhered to the substrate and changes in water vapor transmission rates might have led to increased deterioration of the adobe.

The acrylic and vinyl acetate render additives were designed to improve the strength of the material to which they were added by essentially acting as flexible adhesives; these included panels 2 (El Rey Superior 200), 3 (Daraweld-C), and 10 (Soil Seal Concentrate). None of the products have much, if any, water repellency, and thus eroded in a manner more similar to unamended earth. The acrylics and vinyl acetates fill the pores of the material to which they are applied and do reduce the water vapor transmission rate, but they allow water to pass and are generally stable in an exterior environment.

Two additives were designed to act as both a flexible adhesive and to impart some water repellency; these include panels 4 (asphalt emulsion) and 9 (agave juice). The asphalt emulsion did impart these new properties to the earthen render, but the cactus juice/mucilage was not of the correct quality and/or quantity to have any effect.

In summary, the most materially compatible protective coatings do not appreciably improve the weathering characteristics of the adobe or earthen render. The acrylic, vinyl acetate, asphalt, and agave render additives are less materially compatible and may adversely alter the properties of the earth, but may also significantly improve its weathering characteristics. The spray and roll-on applications form highly incompatible surface crusts or skins which, when breached, may cause accelerated erosion of the unprotected adobe or earthen render.

Texture

The visual aesthetic of many adobe ruins is tied to the image of crumbling adobe bricks. The construction logic and original form of the structures are also revealed by the adobe courses. The chief objection to amended earthen renders, which otherwise can work very well, is that they conceal the adobe coursing. Thus part of the Adobe Test Wall Project – Phase I was to test six sprays and roll-on applications which would protect the walls but allow the adobe and/or coursing to be seen. These treatments were applied directly to the adobe walls with no intervening protective coating of unamended earth, allowing both the adobe and the coursing to be seen through a clear coat (panels 6, 7, 11, and 12: K & E Mineral Sealer, linseed oil, Silicote, and Seal-Krete) or just the coursing to be seen underneath a heavier coat (panels 5 and 8: Acryl 60/Super Quickseal and Thorocoat). Three of these applications performed better than unamended earthen render: Silicote, Acryl 60/Super Quickseal, and Thorocoat. However, three amended earthen renders performed much better than the best of these.

The most compatible alternative to leaving the adobes exposed is to apply an unamended earthen render, but the working life of unamended earth can be too short-lived to provide an effective protective coating. Thus additives are added to increase the working life of the render. The texture of almost all of the amended renders tested for this project (panels 2, 3, 4, 9, 10, and 13: El Rey Superior 200, Daraweld-C, asphalt emulsion, agave juice, Soil Seal Concentrate, and straw) both new and through the years of erosion, was identical or reasonably similar to the unamended earthen render.

Weathering patterns

On average, the west faces of all of the panels displayed the most serious erosion and the south faces the least (see Table 30). This was quite evident throughout the course of the experiment, and is confirmed by the weather data for the area. Most of the storms are from the west, northwest, and southwest, thus the west walls are most exposed to the abrasive and erosive action of wind and wind-borne particulate, rain, and hail. The south walls are sheltered, warm and dry. On average, north and east faces displayed the same level of moderate erosion. These are the cool wall faces, particularly the north wall face; snow is slower to melt and moisture is slower to evaporate. Thus water-driven deterioration mechanisms like freeze-thaw cycling are more common, leading to increased erosion of these wall faces.

Failure of the panels almost always began because of failure at the wall crest, even in amended render panels which otherwise performed quite well. Failure often began in the form of two long, horizontal cracks which developed at the juncture of the vertical wall face and the wall top. This cracking was probably caused by shrinkage after application, as the horizontal surface of the wall top dried much more quickly than the vertical wall faces, and/or by differential thermal expansion through time as the wall top, directly exposed to the sun for the entire day, expanded much more in the heat than the vertical surfaces, which the sun always struck at an oblique angle and most of which were shaded for part or all of the day. To ameliorate this problem, conditions of cure could be more carefully controlled or stronger additives could be applied just at the wall tops. The common, if often unintentional, solution to this problem is to avoid a continuous coat of render from one side of the wall to the other by capping the wall with adobe blocks.

The manner in which a protective coating deteriorates has a large impact on the visual aesthetics of a site. Thus the weathering pattern of any new materials at an earthen site should be as close to unamended earth as possible in order to maintain aesthetic integrity. Of the thirteen protective coatings, four of the amended earthen renders weathered in a gradual, uniform, and naturalistic manner, and were most similar to panel 1 (unamended earth); these included panels 2 (El Rey Superior 200), 9 (agave juice), 10 (Soil Seal Concentrate), and 13 (straw). Two of the amended renders, panel 3 (Daraweld-C) and panel 4 (asphalt emulsion) tended to separate in sheets at the render layer interfaces on certain exposures; as mentioned above, this was probably a result of poor adhesion between the amended render layers.

All of the sprayed render applications eroded in a visually disruptive fashion, developing deep pits and fissures along shrinkage cracks or areas of weakness; these included panels 6 (K & E Mineral Sealer), 7 (linseed oil), 11 (Silicote), and 12 (Seal-Krete). This pattern of deterioration was caused by the poor depth of penetration of the sprays and the resultant formation of harder and less permeable surface crusts over the relatively soft earthen render. When the surface crusts were breached, the erosion of the render was accelerated as water was directed into these areas. In contrast, the sprayed, unrendered adobe walls did not develop pits and fissures because the adobe was harder and more erosion resistant than the earthen render. But runnels were found only on these walls, again a result of water being channeled along weaknesses in the harder and less permeable surface crust and eroding the adobe.

The weathering patterns of the roll-on applications (panels 5 and 8, Acryl 60/Super Quickseal and Thorocoat) seemed more appropriate to a modern building: the surfaces of the protective coatings displayed no erosion, even after fifteen years, but some of the panels developed blisters and all of the panels failed by delaminating in rubbery sheets from the adobe walls. Again this was probably caused by poor adhesion between the protective coating and the earthen render or adobe.

Quantitative erosion

To record quantitative erosion, five aluminum rods were placed in each protective coating panel, two at 15.24 cm (6.0”) above grade, one in the center at 76.20 cm (30.0”) above grade, and two near the top at 132.08 cm (52.0”) above grade. The final layer of each protective coating was brought flush with the ends of the monitoring rods. (In panels that were divided in half to test two variations of the same protective coating, each half contained a rod at the wall base and at the wall top, while the central rod was placed along the border between the two coatings. Thus each half effectively had three monitoring rods rather than five). Erosion measurements were recorded in March 2000 (Appendix E); because many of the rods were loose, particularly towards the wall tops, measurements should only be regarded as approximate. As well, the panels deteriorated very irregularly and the measurements taken at the five rods (or in many cases three rods) sometimes do not reflect the overall deterioration pattern of each protective coating, particularly for spray applications. But in general, the quantitative data does confirm the qualitative observations made above.

The data indicates that among the thirteen panels, north and west wall faces generally displayed the greatest erosion (see Appendix E). Weather data indicates that these faces are the most exposed to wind and precipitation, particularly the west. Additionally, the north wall is in the shade for much of the year, particularly in winter when rain and snow accumulate at the wall base, making freeze-thaw cycling an important deterioration mechanism. Also the high temperature gradient between the south and north faces, and to a lesser extent the east and west faces (both of which are warmed directly by the sun during the day), exerts mechanical stress on the weak earthen materials, leading to cracking and subsequent erosion.

Within each panel, wall tops always displayed the greatest erosion. In fact, most of the monitoring rods have been lost from the top of the west wall face, a testament to the fact that it was the most exposed to wind and precipitation. Erosion at mid-wall was generally low and similar to erosion at the wall base when those rods were exposed. However, most of the wall base rods were buried beneath grade due to the deposition of material from the eroding panel above and the accumulation of wind-blown particulate. Thus many of the wall bases at this height have essentially been backfilled and erosion has stopped. Wall base rods on the south face of test wall 1, the most sheltered exposure, were exposed because erosion on the wall above was minimal and wind-blown deposits did not accumulate. Despite remaining exposed, wall base erosion on the south face was low except on panels 9 and 12 (agave juice and Seal-Krete) which displayed poor overall erosion resistance.

Panels also displayed consistent deterioration patterns within each category of treatment (amended earthen render, roll-on application, and spray application). To illustrate this, data for the control panel (unamended earthen render) and three of the protective coating treatments on test walls 1 and 2 were graphed (Figures 4a and 4b). These are cross sections through panels 1 (unamended earthen render), 2 (earthen render amended with 5% and 10% solutions of El Rey Superior 200), 5 (adobe and earthen render sprayed with Acryl 60 and then covered with a roll-on coating of Super Quickseal), and 6 (adobe and earthen render sprayed with K & E Mineral Sealer). Again, it should be noted that the panels deteriorated very irregularly, and the measurements taken at the monitoring rods do not reflect the overall deterioration pattern of each panel. Because of this the figures in some cases belie the statements made above; the latter should be considered more accurate because they were derived from analysis of all of the quantitative data, which was then considered in light of the qualitative data.

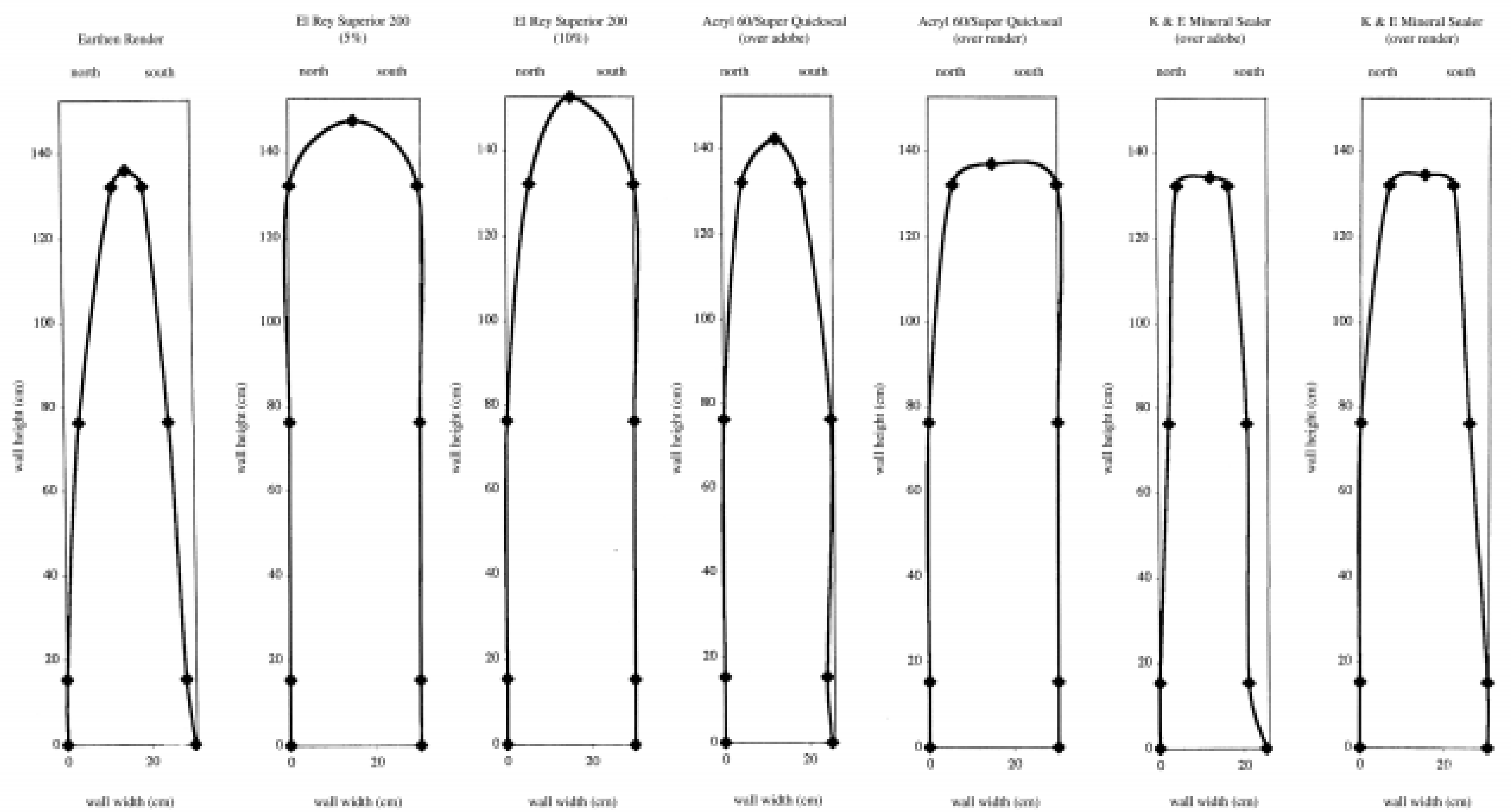

Figure 4a. Cross sections of representative panels from test wall 1, the protective coating experiment, which were derived using the 2000 data from the aluminum monitoring rods installed in the walls during construction. The rectangular outlines indicate the approximate original dimensions of the walls and the heavier lines the approximate present dimensions of the walls. The cross sections are taken through panels 1 (unamended earth), 2 (earthen render amended with El Rey Superior at 5% and 10%), 5 (adobe and earthen render sprayed with Acryl 60 and then coated with Super Quickseal) and 6 (adobe and earthen render sprayed with K & E Mineral Sealer).

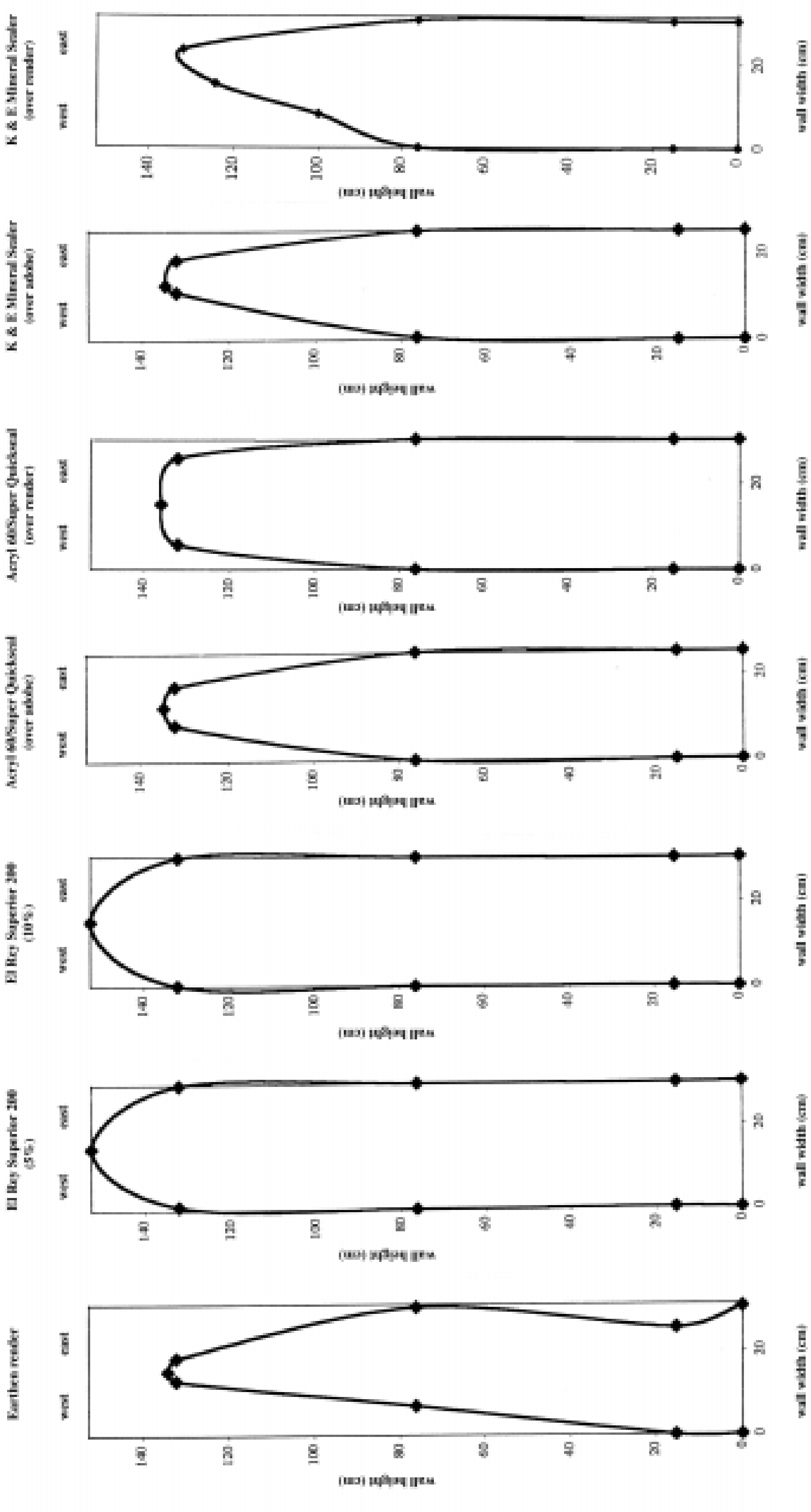

Figure 4b. Cross sections of representative panels from test wall 2, the protective coating experiment, which were derived using the 2000 data from the aluminum monitoring rods installedin the walls during construction.The rectangular outlines indicate the approximate original dimensions of the walls and the heavier lines the approximate present dimensions of the walls.The cross sections are taken through panels 1 (unamended earth), 2 (earthen render amended with El Rey Superior at 5% and 10%), 5 (adobe and earthen render sprayed with Acryl 60 andthen coated with Super Quickseal) and 6 (adobe and earthen render sprayed with K & E Mineral Sealer).

Nevertheless, it can be observed that amended earthen renders, and El Rey Superior 200 in particular, provide the best erosion resistance. On all exposures, almost no material has been lost from the vertical faces of the walls while the wall tops are often at their original height. Roll-on coatings applied over earthen renders, as illustrated by Acryl 60/Super Quickseal, provide a comparable level of protection on the vertical wall faces but do not protect the wall top much better than unamended earthen render. Roll-on coatings applied directly to the adobe walls do not perform as well, although they do provide more erosion resistance on vertical wall faces than do unamended earthen renders or sprays. Spray coatings applied over both adobe and earthen render, as typified by K & E Mineral Sealer, appear to provide a small increase in erosion resistance in comparison with unamended earthen renders. However, this is contradicted by qualitative observations: the spray applications tend to fail completely in localized areas a short time after application, and provide much less overall erosion resistance than the unamended earthen renders.

5.0 Summary and Analysis of Wall Cap Experiment

Caps have long been used to protect unroofed adobe wall tops and have been composed of a wide range of materials. While caps do protect the tops of walls and prevent them from losing height, some capping materials appear to accelerate the erosion of the adobe immediately beneath the cap, causing a reduction in wall width which can sometimes threaten to undermine the cap. The cause of this accelerated erosion has been attributed to moisture trapped in the adobe beneath the less permeable cap and increased surface runoff from the less permeable cap onto the soft adobe. Test wall 3 was designed to assess the relative effectiveness of four caps at protecting the underlying adobe wall, to determine the extent to which they caused accelerated erosion at the cap/wall interface, and to compare the amount of erosion from both the capped wall tops and vertical wall faces with that of uncapped test wall 5.

The caps were composed of asphalt amended adobe bricks, cement-based render, and brick coping. The test wall measured 20.0’ long x 5.0’ high x 10” wide and was aligned on an east-west axis. It was constructed of unamended adobes laid in unamended earthen mortar, and was set on a foundation of two courses of unamended adobes. No render was applied to the wall faces. The wall was then divided into four panels, each measuring 5.0’ x 5.0’ x 10”; a different wall cap was then constructed on the top of each panel (see Figure 2). Each capped panel was given a three-character code: the first number represents the test wall number, the letter represents the cardinal direction, and the second number represents the panel number within the wall (e.g., 3S4 is test wall 3, south face, cap 4). Each cap is fully described below. Throughout the course of the project, each cap was monitored for qualitative erosion and quantitative erosion (see Section 3.0 for a discussion of monitoring procedures).

5.1 Asphalt stabilized adobe cap: 3N1, 3S1

Panels 3N1 and 3S1 were capped with one course of asphalt emulsion-stabilized adobe bricks laid in earthen mortar amended with 1:5 asphalt emulsion in water. The capping adobes were laid parallel with the unamended adobes and were flush with the north and south faces of the wall (see Figure 2).

After one year of exposure, some erosion was observed at the unamended adobe-stabilized cap interface. On the south face, the top course of unamended adobe had eroded as much as 10 mm. On the north face, erosion was as deep as 50 mm. After nine years of exposure, erosion on the south wall at the wall-cap interface averaged 7.0 cm; at 20 cm below the interface, erosion averaged 2.5 cm. On the north wall, erosion also averaged 7.0 cm at the interface, but at 20 cm below the interface erosion was greater than on the south face and averaged 4.5 cm (Taylor 1994) (Table 31).

Table 31. Erosion below caps on the north and south faces of Fort Selden test wall 3 (in centimeters) in 1994.

North wall face Location	**Erosion below cap** (cm) Stabilized adobe cap	Stabilized, sloped adobe cap	Cement-based cap	Brick cap
Cap-wall interface	7.0	5.0	4.0	3.0
20 cm below interface	4.5	2.5	2.5	2.5

South wall face Location	**Erosion below cap** (cm) Stabilized adobe cap	Stabilized, sloped adobe cap	Cement-based cap	Brick cap
Cap-wall interface	7.0	7.0	4.5	2.5
20 cm below interface	2.5	3.0	1.2	1.2

5.2 ASPHALT STABILIZED AND SLOPED ADOBE CAP: 3N2, 3S2

Panels 3N2 and 3S2 were capped with one course of asphalt emulsion-stabilized adobe bricks laid in earthen mortar amended with 1:5 asphalt emulsion in water. The capping adobes were laid perpendicular to the unamended adobes and extended 2” beyond the wall plane on the north and south faces. The adobe brick was also sloped so that the north edge was one inch lower than the south edge (see Figure 2).

After one year of exposure, no erosion was observed at the unamended adobe-stabilized cap interface. However, erosion was occurring at the base of the north wall, where runoff from the sloped cap splashed back against the wall. After two years, this cap had caused only minimal erosion in the underlying adobe wall and was causing the least erosion of the four caps. But after five years,

> the cap with the overhang [was] failing in part because the south overhanging portion which slopes to the north has no drip edge, causing water to run back under the overhang and penetrate the unamended wall top. On the north side of this same cap, moisture is eroding the unamended wall top, probably because the overhang does not extend out sufficiently away from the wall (Taylor 1990:388).

After nine years of exposure, erosion on the south wall at the wall-cap interface averaged 7.0 cm; at 20 cm below the interface, erosion averaged 3.0 cm. On the north wall the level of erosion was much less, averaging 5.0 cm at the interface and 2.5 cm at 20 cm below the interface (Taylor 1994) (see Table 31).

5.3 SLOPED CEMENT-BASED CAP: 3N3, 3S3

Panels 3N3 and 3S3 were capped with Portland cement-based render. The head joints of the top course of unamended adobe were left open during construction and were then filled with cement-based render when the cap was applied. The cap was 4” high at the center and was sloped to the north and south to shed water. The cap and the filled head joints were made flush with the north and south faces of the unamended adobe wall.

After one year of exposure, erosion was evident at the unamended adobe-cement cap interface. On both the north and south faces, erosion was as deep as 20 mm. After two years and five years of exposure, erosion was greater but the pattern remained the same. After nine years of exposure, erosion on the south wall at the wall-cap interface averaged 4.5 cm; at 20 cm below the interface, erosion averaged 1.3 cm. On the north wall, erosion averaged 4.0 cm at the interface; at 20 cm below the interface, erosion averaged 2.5 cm (Taylor 1994) (see Table 31). After fifteen years of exposure, this portion of the wall collapsed; it was probably pulled down with the adjacent heavy brick cap during a strong wind. The light color and the weathering pattern of the cement-based cap were not compatible with that of the unamended adobe wall. The cement-based cap was much harder than the unamended adobe and displayed no surface erosion after fifteen years of exposure, while the adobe wall had eroded in soft contours.

5.4 BRICK CAP: 3N4, 3S4

Panels 3S4 and 3N4 were capped with a Territorial style, denticulate brick coping laid in Portland cement-based mortar. The cap was three courses high (about 8”) and extended 2” beyond the wall plane on the north and south faces (see Figures 1 and 2).

After one year of exposure, erosion was evident at the unamended adobe-brick cap interface. On the north face, erosion was as deep as 30 mm in the top course of unamended adobe; on the south face, erosion was as deep as 15 mm. After two and five years of exposure, erosion was greater but the pattern remained the same. After nine years of exposure, erosion on the south wall at the wall-cap interface averaged 2.5 cm; at 20 cm below the interface, erosion averaged 1.2 cm. On the north wall, erosion averaged 3.0 cm at the interface; at 20 cm below the interface, erosion averaged 2.5 cm (Taylor 1994) (see Table 31). After fifteen years of exposure this portion of the wall collapsed, probably a result of winds and the weight of the cap.

5.5 CONCLUSIONS AND RECOMMENDATIONS

After five years of weathering, all of the caps protected the top of the unamended adobe wall but did not prevent erosion of the unamended adobe immediately beneath the cap, and in some cases may have accelerated the rate of erosion. In addition to the erosion caused by the impact and/or runoff of surface water, flaking was noted in the adobe beneath all caps on the north side of the wall. While the exact deterioration mechanisms cannot be determined without further experimentation and environmental monitoring, this pattern of flaking can probably be attributed to increased wetting/drying and freeze/thaw cycling on the cool northern exposure, a situation exacerbated by the tendency of the caps to trap moisture and direct runoff onto the adobe wall.

Among the four caps, the brick cap (panel 4) caused the least erosion at the cap-wall interface and in the adobe 20 cm below the interface on both the north and south exposures (see Table 31). The brick cap extended beyond the adobe wall plane by 2” on either side and provided a drip edge which prevented water from reaching the cap-wall interface. However, the weight of the brick cap probably contributed to the collapse of the wall after about fifteen years of exposure. Erosion was greater on the north face than on the south face, as was expected given the weather patterns at the site.

After the brick cap, the cement-based cap caused the least erosion in the underlying adobe wall. Erosion was slightly greater on the north face of the wall. However, the color and weathering pattern of the cement-based cap were not compatible with the unamended adobe wall.

The asphalt stabilized adobe cap placed flush with the wall (panel 1) and the asphalt stabilized, sloped, and overhanging adobe cap (panel 2) caused the most erosion in the underlying adobe wall after nine years of exposure. Panel 2 showed initial promise, but over time its design still allowed enough water to reach the south cap-wall interface to cause significant erosion. On the north side, however, where the cap sloped downward like an eave, erosion was reduced because less moisture reached the interface and/or because the eave sheltered the upper wall from the wind.

To compare erosion in capped walls and uncapped walls after fifteen years of exposure, cross sections were measured through three panels/walls: the two remaining capped panels in test wall 3 (panel 1, the stabilized adobe cap, and panel 2, the stabilized and sloped adobe cap) and test wall 5, an uncapped adobe wall. For the cross sections, measurements were taken at 5.08 cm (two inch) intervals along a vertical axis and the results were graphed (Figure 5); all measurements were taken by the Fort Selden State Monument staff in June 2000 (see Appendix E). All of the panels/walls were constructed of unrendered adobe; the two panels in test wall 3 were built on adobe foundations while test wall 5 was built on a raised stone foundation. Present grade on the capped walls occurs at about 20 cm above original grade; present grade on test wall 5 is still below the top of the stone foundation.

The cross sections illustrate that caps do reduce erosion on the wall tops. After fifteen years of exposure, the walls beneath the two caps have lost no height, while the uncapped wall has lost 23% of its height. The cross sections also illustrate that of the two remaining capped walls, the wall with the asphalt stabilized (and unsloped) cap displayed the least erosion on the upper vertical wall faces.

It is still uncertain, however, to what extent caps might accelerate erosion of unamended adobe walls. Because the upper vertical faces of walls are more exposed, they naturally lose more material than the lower vertical wall faces on both capped and uncapped walls. Given the lack of data from the early years of the experiment when the rates of erosion from the vertical faces of uncapped and capped walls could be most accurately compared, it is not possible to distinguish between natural erosion and any accelerated erosion which may be caused by the caps. However, the cross sections illustrate that the patterns of erosion

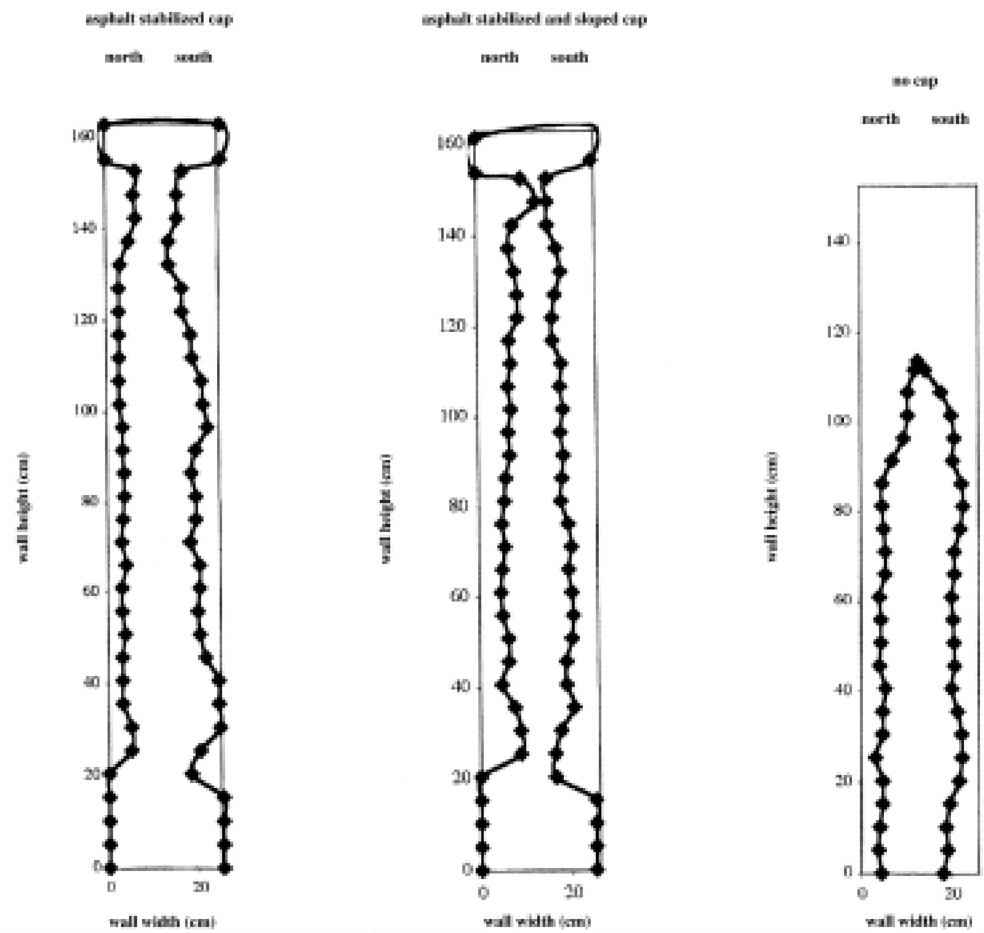

Figure 5. Cross sections of the two remaining caps on test wall 3, the wall cap experiment, and test wall 5, the uncapped control, which were derived from field measurements taken in July 2000. The rectangular outlines indicate the approximate original dimensions of the walls and the heavier lines the approximate present dimensions of the walls; none of the walls were rendered. The cross sections are taken through panels 3(N/S)1 (asphalt stabilized cap), 3(N/S)2 (asphalt stabilized and sloped adobe cap), and 5(N/S) (no cap).

on the upper faces of capped and uncapped walls are similar. In fact, the uncapped wall appears to lose material more rapidly towards the wall top, contradicting the theory that caps cause accelerated erosion.

6.0 SUMMARY AND ANALYSIS OF WALL FOUNDATION EXPERIMENT

Test walls 4 through 15 were used to experiment with twelve different wall foundation treatments, measure the rate of capillary rise through each foundation, and assess the effects of moisture on the walls. Treatments ranged from traditional foundations (adobe, stone) to more modern designs (concrete stem walls, vapor barriers) (Table 32). These treatments were selected "upon the basis of modern and historic practices, as well as myths, facts, arguments, and fantasies" about adobe wall foundations (Taylor 1987b: 33). Each wall foundation is described fully in the following sections.

The twelve test walls measured 5.0' long x 5.0' high; width varied from 10" (unrendered walls) to 12" (rendered walls). All walls were aligned on an east-west axis in order to expose each treatment to the north and south (see Figure 2). Each test panel was given a two-character code: the number represents the test wall number and the letter represents the cardinal direction (e.g., 9N is test wall 9, north face). Throughout the course of the project, each wall was monitored for qualitative erosion and moisture content (see Section 3.0 for a discussion of monitoring procedures).

Table 32. Wall foundation treatments applied to Fort Selden test walls 4 – 15 (adapted from Taylor 1990).

Test wall	Foundation	Upper wall
4	Concrete footer and concrete block stem wall	Unamended adobe wall with cement-based render
5	Stone footer and stem wall laid in unamended earthen mortar	Unamended adobe
6	Base course (gravel/sand mixture)	Unamended adobe
7	Unamended adobe laid in unamended earthen mortar	Unamended adobe
8	Unamended adobe surrounded with sub-surface apron of polyethylene sheeting sloping away from the wall	Unamended adobe
9	Unamended adobe surrounded with a sub-surface apron of earth amended with Union Carbide R-274, sloping away from the wall	Unamended adobe
10	Unamended adobe surrounded by gravel drained by perforated plastic pipe, which lead to a sump (French drain)	Unamended adobe
11	Unamended adobe	Unamended adobe wall with cement-based render
12	Unamended adobe artificially coved and surrounded with a poured concrete wainscot	Unamended adobe
13	Stone laid in unamended mortar, the adobe wall above artificially coved and surrounded with a poured concrete wainscot	Unamended adobe
14	Unamended adobe	Unamended adobe with unamended earthen render
15	Unamended adobe covered with parge plaster and an asphalt vapor barrier	Unamended adobe

6.1 REINFORCED CONCRETE FOUNDATION, CEMENT-BASED RENDER: 4N, 4S

The foundation of test wall 4 was composed of a

> cement footer 16 inches wide by 8 inches high by 6 ft long with 12 ft of No. 4 rebar enclosed in the cement 4 inches from either side. Four cement blocks (10 x 8 x 16 inches) were laid on top of the wet footer and leveled for the first course of the stem wall. The second course of the stem wall includes three full 10 x 8 x 16 cement blocks and two 10 x 8 x 8 cement blocks at each end. The top of the second course is 6 inches above the present ground surface. No mortar was used between the two cement block courses, however all cells of both courses were filled with cement (Gossett and Gossett 1985: 7).

The upper wall was composed of unamended adobe laid in earthen mortar. Galvanized hex mesh was then secured to the wall with nails and three layers of cement-based render, each 1/3" thick, were applied to the entire wall beginning approximately 4" below grade.

During the first year of the project, moisture readings were taken 75 times. The results were summarized in the first status report:

> The foundation of this wall generally retained more moisture than those without a cement stucco coating. However, practically no measurable readings were obtained above sensor #3 which is placed at grade. Measurable moisture did not seem to correlate with periods of precipitation.
>
> This would indicate that with the limited instrumentation and occurrences of precipitation, no measurable amount of moisture can be detected above grade within the wall. The measurable moisture readings were recorded from sensors placed in the foundation, and especially from sensor #3 (Taylor 1986c: 39).

No basal erosion was apparent in the photographic documentation taken from 1985 through 1991 (see Appendix G). In 2000, no basal erosion or other accelerated deterioration was noted in the test wall.

6.2 STONE FOUNDATION: 5N, 5S

The foundation of test wall 5 was composed of an

> angular rock footer laid with unamended adobe mortar which is 16 inches wide by 8 inches high by 5 and 1/2 ft long. The stem wall is also made from angular rock laid with unamended mud mortar and is 10 inches wide, 8 inches high and 5 ft long. The footer was allowed to dry for 24 hours before the stem wall was constructed (Gossett and Gossett 1985: 7-8).

The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. The results were summarized in the first status report:

> Measurable moisture was only recorded from sensors placed at grade and subgrade (sensors 1-3). Moisture readings do not seem to correlate with periods of rainfall. Only unmeasurable traces of moisture were recorded above grade (Taylor 1986c: 41).

No basal erosion was apparent in the photographic documentation taken from 1985 through 1991 (see Appendix G). In 2000, very limited basal erosion was noted on the north face of the test wall.

6.3 GRAVEL AND SAND FOUNDATION: 6N, 6S

The foundation of test wall 6 was composed of

> 3/4 inch gravel/sand placed in a trench 14 inches wide, 12 inches high and 6 ft long to grade. The gravel was [dampened] and compacted (Gossett and Gossett 1985: 8).

The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. Measurable moisture was not recorded above grade in this wall (Taylor 1986c: 43). No basal erosion was apparent in the photographic documentation taken from 1985 through 1987. Beginning in about late 1987 or early 1988, limited basal erosion was apparent on the both the south and north faces of the wall (see Appendix G). By 2000, the test wall had collapsed.

6.4 ADOBE FOUNDATION: 7N, 7S

The foundation of test wall 7 was composed of two unamended adobes laid in unamended earthen mortar to grade. The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. Almost no detectable amounts of moisture were measured in this wall, even in the subgrade cells (Taylor 1986c: 44). No basal erosion was apparent in the photographic documentation taken from 1985 through 1991 (see Appendix G). In March of 1991, the test wall collapsed.

6.5 POLYETHYLENE SHEETING APRON: 8N, 8S

The foundation of test wall 8 was composed of

> 2 unamended adobes laid with unamended mortar to grade. A polyethylene vapor barrier was placed on each side of the wall, sloping away from the wall from grade to a depth of 12 inches below surface. The sheets are 6 mil and measure 3 ft by 5 ft on either side (Gossett and Gossett 1985: 8).

The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. Almost no detectable amounts of moisture were measured in this wall, even in the subgrade cells (Taylor 1986c: 45). In the photographic documentation taken from 1985 through 1991, basal erosion was apparent in both the north and south faces of the test wall beginning in July of 1987, during the rainy season (see Appendix G). Basal erosion was moderate when documentation was discontinued in 1991. By 2000, the test wall had collapsed.

6.6 AMENDED EARTH APRON: 9N, 9S

The foundation of test wall 9 was composed of two unamended adobes laid with unamended mortar to grade. An adobe mortar amended with Union Carbide R-274, an "organosilane ester with proprietary additive" in ethanol, was placed on both sides of the wall as a moisture barrier (Material Safety Data Sheet, see Appendix D). Specifications called for Union Carbide RE280, but this product was obsolete and had been replaced by R-274. The amended earth apron was "4 inches thick, 5 ft long and 3 ft wide on each side. It slopes from grade at the wall to 10 inches below surface" (Gossett and Gossett 1985: 8). The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. The results were summarized in the first status report:

> Detectable amounts of moisture were recorded for sensors placed at and below grade, as well as detectable amounts of moisture recorded from sensors 4 and 5 on one occasion. Detectable moisture readings did not seem to correlate with periods of rainfall (Taylor 1986c: 46).

No basal erosion was apparent in the photographic documentation taken from 1985 through 1987. Beginning in about late 1987 or early 1988, very limited basal erosion was apparent on the south face of the wall (see Appendix G). By 2000, the test wall had collapsed.

6.7 FRENCH DRAIN: 10N, 10S

The foundation of test wall 10 was composed of

> 3 courses of unamended adobes laid with unamended adobe mortar to grade. A French drain (sump), 24 inches deep, 18 inches wide at the bottom and 24 inches wide at the top

> was placed on the west end beginning 12 inches from the wall. This sump was filled with 3 inch diameter river cobbles. Along both sides of the wall, trenches (12 inches by 6 inches by 6 ft) were excavated. Three inches of 3/4 inch gravel was placed in the trench bottoms and 1 piece of 3 inch by 6 ft long perforated PVC drain pipe was laid on the gravel beds on both wall sides. The trenches were then filled with 3/4 inch gravel to grade. These drains extended into the French sump and were sloped 1/4 inch per ft to the west (Gossett and Gossett 1985: 8-9).

The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. No detectable amounts of moisture were recorded from cells at and above grade, and all readings taken after the wet month of August were undetectable (Taylor 1986c: 47). No basal erosion was apparent in the photographic documentation taken from 1985 through 1991 (see Appendix G). In 2000, moderate basal erosion was noted on both the north and south faces of the test wall.

6.8 ADOBE FOUNDATION, CEMENT-BASED RENDER: 11N, 11S

The foundation of test wall 11 was composed of two unamended adobe courses laid in unamended earthen mortar to grade. The upper wall was composed of unamended adobe laid in earthen mortar. Galvanized hex mesh was then secured to the wall with nails and three layers of cement-based render, each 1/3" thick, were applied to the entire wall beginning approximately 4" below grade.

During the first year of the project, moisture readings were taken 75 times. Small amounts of moisture were recorded subgrade between March and July, but no detectable amounts of moisture were recorded above cell 3 (at grade) (Taylor 1986c: 48). No basal erosion was apparent in the photographic documentation taken from 1985 through 1991 (see Appendix G). In 2000, no basal erosion or other accelerated deterioration was noted in the test wall.

6.9 CONCRETE WAINSCOT: 12N, 12S

The foundation of test wall 12 was composed of

> 2 unamended adobe courses laid with unamended adobe mortar to grade. The wall base was artificially coved [to a depth of approximately 3 inches] at the first two courses up from grade. A wooden form was constructed around the entire wall and a concrete [wainscot] 16 inches high, 5 ft 8 inches long and 18 inches wide was poured to cover the basal coving. The cement was poured from the base of the foundation. The top of the cement [wainscot] was sloped downward from the wall for drainage. A metal lath strip over a 2 x 4 was used to rasp the adobes for the artificial coving (Gossett and Gossett 1985: 9).

The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. The results were summarized in the first status report:

> Detectable amounts of moisture were recorded in sensors #1 through 5. Sensor #5 is located just below the top of the cement wainscot. The readings indicate that moisture is retained in the lower portions of the wall where the wainscot is located (Taylor 1986c: 49).

Because of the minimal results obtained with the thermistor soil cells, test wall 12 was artificially flooded to determine if the cells would detect larger volumes of moisture. An earthen berm was built up around the wall and was filled with water for a period of six days in December, 1987. The cells were read almost daily for the next month; use of the cells was discontinued after January 19, 1988 (Table 33).

The electrical resistivity data indicates that moisture levels at cells 1, 2, and 3 slowly but steadily increased from December through January. By January 12th, capillary rise had reached cell 4. Thus capillary rise in the adobes was very slow, and was still taking place when the use of the cells was

Table 33. Electrical resistance levels in Fort Selden test wall 12, before and after artificial flooding (x 10,000 ohms).

Date	**Soil cell #**								**Moisture**
	1	2	3	4	5	6	7	8	
12/1/87	T	T	T	T	T	T	T	T	
12/3/87	3.5	3.0	T	T	T	T	T	T	flooded
12/4/87	6.5	200	T	T	T	T	T	T	flooded
12/5/87	3.5	100	200	T	T	T	T	T	flooded
12/6/87	2.5	90	200	T	T	T	T	T	flooded
12/7/87	2.25	35	T	T	T	T	T	T	flooded
12/8/87	2.25	17	200	T	T	T	T	T	flooded
12/16/87	2.5	4.0	100	T	T	T	T	T	1.3”
12/17/87	2.9	4.0	200	T	T	T	T	T	
12/19/87	2.5	3.7	200	T	T	T	T	T	
12/20/87	2.5	3.5	100	T	T	T	T	T	.04”
12/21/87	2.7	3.7	60	T	T	T	T	T	.12”
12/22/87	2.5	3.6	50	T	T	T	T	T	
12/28/87	2.8	3.8	40	T	T	T	T	T	4” snow
12/29/87	2.8	3.8	40	T	T	T	T	T	
12/30/87	2.8	3.8	40	T	T	T	T	T	
12/31/87	2.8	3.8	40	T	T	T	T	T	
1/3/88	2.5	3.5	23	T	T	T	T	T	
1/4/88	2.5	3.5	23	T	T	T	T	T	
1/5/88	2.5	3.5	17	T	T	T	T	T	
1/6/88	2.8	3.7	16	T	T	T	T	T	.06”
1/7/88	2.8	3.7	16	T	T	T	T	T	
1/12/88	2.5	3.7	14	200	T	T	T	T	
1/19/88	2.5	4.0	12	200	T	T	T	T	.14”

T = a reading greater than 200 x 10,000 ohms discontinued. If monitoring of the cells had continued, a good understanding of the rate and height of capillary rise would have been obtained.

As stated in Section 3.5, when the meter read 200 x 10,000 ohms, the soil moisture content was about 3%. When the meter read 2.5 x 10,000 ohms, the soil moisture content was about 10%. The plastic and liquid limits for the adobe sample were 18 and 21 respectively, or 18% and 21% soil moisture (see Section 2.2), making 10% a significant amount of moisture.

No basal erosion was apparent in the photographic documentation taken from 1985 through 1991 (see Appendix G). In 2000, no basal erosion or other accelerated deterioration was noted in the test wall.

6.10 STONE FOUNDATION, CONCRETE WAINSCOT: 13N, 13S

The foundation of test wall 13 was composed of

> an angular rock footer laid with unamended mud mortar 16 inches wide by 8 inches high by 6 ft long. It was allowed to dry for 24 hours before the angular rock stem wall was laid. The stem wall is 10 inches wide, 8 inches high, and 5 ft long and is also laid with unamended adobe mortar. The first two courses above grade were artificially coved [to a depth of approximately 3 inches] and a [wainscot] form was constructed around the entire wall. The [wainscot] is 16 inches high, 18 inches wide, and 5 ft 8 inches long of poured cement which covers the coved area. The [wainscot] was poured from the base of the stem wall. The top was sloped away from the wall for drainage (Gossett and Gossett 1985: 9-10).

The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. The results were summarized in the first status report:

> Detectable moisture readings were obtained from sensors #1 through 4. Sensor #4 is located 4 inches above grade. Measurable readings from #4 indicate that moisture is being retained in the wall where the wainscot surrounds it (Taylor 1986c: 50).

No basal erosion was apparent in the photographic documentation taken from 1985 through 1991 (see Appendix G). In 2000, no basal erosion or other accelerated deterioration was noted in the test wall.

6.11 ADOBE FOUNDATION, EARTHEN RENDER: 14N, 14S

The foundation of test wall 14 was composed of two courses of unamended adobe laid in unamended earthen mortar. The upper wall was composed of unamended adobe laid in unamended earthen mortar, to which 3 coats of unamended earthen render, each 1/3” thick, were applied.

During the first year of the project, moisture readings were taken 75 times. Small amounts of moisture were recorded subgrade between March and July, but no detectable amounts of moisture were recorded above cell 2 (4” below grade).

No basal erosion was apparent in the photographic documentation taken from 1985 through 1987. Beginning in September 1988, after the rainy season, moderate basal erosion was apparent in the earthen render and eventually in the adobe on both the north and south faces of the wall (see Appendix G). By 2000, the test wall had collapsed.

6.12 ADOBE FOUNDATION WITH ASPHALT VAPOR BARRIER: 15N, 15S

The foundation of test wall 15 was composed of

> 2 courses of unamended adobe laid with unamended mortar. From the bottom of the foundation to the first course above grade, a parge plaster was placed around the entire wall. The plaster mixture is composed of cement, sand, and water at a ratio of 1 part cement to 5 parts sand mixed with water to a usable consistency. It is approximately 1/2 inch thick and troweled smooth. After drying for 24 hours it was then coated with liquid asphalt roof coating (Gossett and Gossett 1985: 10).

The upper wall was composed of unamended adobe laid in unamended earthen mortar.

During the first year of the project, moisture readings were taken 75 times. Small amounts of moisture were recorded subgrade between March and July, but no detectable amounts of moisture were recorded above cell 3 (at grade).

No basal erosion was apparent in the photographic documentation taken from 1985 through 1987. Beginning in July of 1989, very limited basal erosion was apparent on the north face of the wall (see Appendix G). By 2000, the test wall had collapsed.

6.13 CONCLUSIONS AND RECOMMENDATIONS

Based upon the flooding and subsequent monitoring of test wall 12, the thermistor soil cells in test walls 4-15 were functioning well, and were sensitive enough to record as little as 3% moisture. Thus the reason for the limited data was that there was not significant moisture in the walls. However, these small amounts of moisture were sufficient to initiate the process of basal erosion, as documented in the photographs of the walls taken from 1985 to 2000.

Basal erosion proceeds much more rapidly on the historic walls of the fort; unamended earthen repairs show signs of basal erosion sometimes within a year of application. A frequently speculated source of moisture is the water supplied to the cottonwood trees on the north and west sides of the parade ground, which were planted in 1974. (Occupation-era photographs showed that cottonwoods had been planted in these locations, and the present trees were planted in an effort to restore that landscape.) Then, as now, these trees are too far from the Rio Grande to thrive without additional water. Historically, soldiers hauled the necessary water, but now underground pipes supply it to the bases of the trees during the summer months; the trees aren't watered during the cooler months. But wall base erosion was a major problem at the site in 1972, long before the trees were planted. In their favor, the trees do draw water from the soil, help to define the historic landscape, and provide a framework for interpreting the scattered wall fragments.

A more important source of moisture may derive from the fact that the soils in the area have clays in the top 24 inches and gravels below the top soil level (Gossett and Gossett 1985: 5). Thus surface water is retained in the topsoil and percolates slowly through the clayey layers. The historic walls are not affected by flooding from the river and the water table is too deep for capillary rise to affect the wall bases. So the moisture in the historic walls probably comes from surface water or retained soil moisture following precipitation events, and perhaps from irrigation of the nearby cottonwood trees (see Section 3.1).

However, the soil around the test walls was disturbed during construction: the clay and gravel layers were mixed and drainage conditions around the walls were improved. Percolation tests conducted for the Phase II test walls indicated that the soil drained at a moderate rate of 1 gallon/15 minutes/square foot. However, the soil stratigraphy was also disturbed because small pits measuring 12” x 12” x 5” were dug for the tests, and drainage rates around the historic walls are probably slower. Through both natural processes and the deposition of clay sized particles at the wall base as the adobe erodes above, the disturbed soil will eventually return to a stratigraphy similar to the historic walls.

Despite the limited results obtained from the soil cells, a number of conclusions can be drawn from the way in which the test wall bases deteriorated as evidenced in the photographic documentation. This information is summarized in Table 34.

Table 34. Maximum height of thermistor soil cell readings and severity of basal erosion in Fort Selden test walls 4-15, 1985-2000.

Test wall	Foundation	Moisture		Basal erosion			
		below grade	above grade	1987	1988	1991	2000
4	Concrete, stem wall and plaster	x					none
5	Stone	x					low
6	Gravel	x		low			collapsed
7	Adobe					collapsed	
8	Adobe with polyethylene apron			low		moderate	collapsed
9	Adobe with amended earth apron		x	low			collapsed
10	Adobe with French drain						moderate
11	Adobe with cement-based render	x					none
12	Adobe with concrete wainscot		x				none
13	Stone with concrete wainscot		x				none
14	Adobe with earthen render	x			moderate		collapsed

15	Adobe with asphalt vapor barrier	x			low		collapsed

Four walls (test walls 4, 11, 12, and 13) showed no signs of basal erosion after fifteen years of exposure; concrete was used for the foundation, wainscot, or render on all of these walls. Obviously concrete prevents basal erosion. However, the problem with concrete (or a cement-based render) is that it forms a relatively impermeable skin around the adobe. As moisture is drawn into the wall through capillary rise or as it enters through cracks in the concrete, it cannot evaporate easily through the concrete skin. This is evidenced by the fact that, of the three walls which had moisture readings above grade, two were walls with concrete wainscots (test walls 12 and 13). As water builds up in the pores of the adobe, the pore pressure can cause further cracks in the concrete. If the adobe becomes saturated, it can exert enough pressure to rupture the concrete skin, and because the liquid adobe is no longer supported by this skin, the wall collapses. Any early signs of deterioration in the adobe wall which might indicate problems are masked by the harder and more durable concrete or cement-based render. In contrast, adobe walls which are not clad in a relatively impermeable skin do not become saturated because water does not build up in the wall. Thus, although the concrete-clad test walls at Fort Selden have not yet collapsed, it may be only a matter of time and/or moisture.

Two other test walls displayed little or no basal erosion after fifteen years of exposure: test walls 5 (stone foundation) and 10 (adobe foundation with French drain). Both of these foundation types have been and continue to be commonly used in adobe construction with few adverse impacts to adobe walls. All of the other Fort Selden test walls collapsed after fifteen years; this may be due to isolated wind shears, but is probably a combination of a weak or inadequate foundation and a compromised wall base.

7.0 SUMMARY AND ANALYSIS OF PROTECTIVE COATINGS AND CAPS APPLIED TO HISTORIC WALLS

Based upon the initial results of the Adobe Test Wall Project – Phase I, six protective coating test panels were applied to the historic walls of Fort Selden in April of 1992. The panels were used to further investigate the performance of different concentrations of El Rey Superior Additive 200, Rhoplex E-330, and El Rey Adobe Protector, a proprietary water repellent (Material Safety Data Sheets for these products are included in Appendix D).

The test panels were applied to the south wall of Features 16 and 17, the Company Quarters. Each panel was five feet wide and continued from the south face of the wall over the crest to the north face. Panel 1 was the control, an unamended earthen render composed of 3 parts soil to 2 parts sharp sand. The soil came from behind the Company Quarters, perhaps from the remnants of historic adobe walls, while the sand was purchased from Las Cruces Transit (Guzman n.d.). Panels 2, 3, 4, and 6 were composed of the same earthen render mix modified with various percentages of acrylic, and Panel 5 was composed of a water repellent applied directly to the historic adobe. Panels 1 through 6 abut each other; panel 1 is western-most, panel 6 eastern-most (Figure 6).

A seventh test involved the installation of unamended adobe block caps; this test was also applied to the south wall of Feature 16, but to the west of the test panels (Figure 7). The soil for these adobes was quarried 1/4 mile west of the site.

Field observations were recorded between 1992 and 1994 (Guzman n.d.), and the condition of the panels was evaluated in 1997 as part of a preservation plan developed for the historic walls (Oliver and Hartzler 1997: 51-57). With the exception of limited erosion, the test panels have changed very little since 1997. For all seven tests, the condition of the material on the north face is slightly worse than the condition of the same material on the south face; the tops of the panels have suffered the greatest erosion.

7.1 TEST PANEL 1: UNAMENDED EARTHEN PROTECTIVE COATING

The protective coating on test panel 1 served as the control, and was composed of unamended earthen render applied in two coats, each 3/4" thick. The unamended protective coating weathered into a pattern identical to the unamended earthen renders used in the Adobe Test Wall Project – Phase I. This weathering pattern was caused by the erosion of the finish coat and the resultant exposure and erosion of cracks in the bottom coat; these cracks were produced as the unamended soil dried and shrank immediately after application. The channels formed by the weathered cracks have caused some erosion of the historic adobe. While both coats are intact on the bottom two-thirds of the wall, the finish coat has eroded from the top third, exposing the bottom coat and leading to the erosional pattern just described.

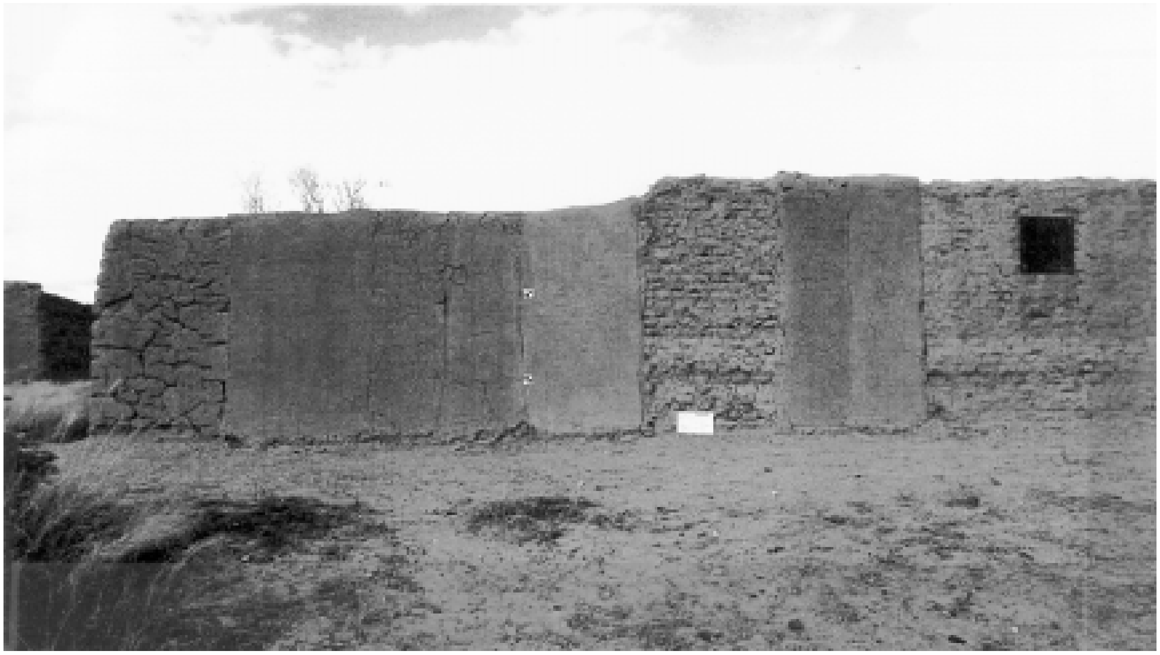

Figure 6. The 1997 appearance of protective coating test panels 1-6, which were applied to historic walls in 1992. Panel 1, the control, is at the left end and panel 6 is at the right end. This photograph is of the south face of the south wall of Features 16 and 17.

Figure 7. The 1997 appearance of the south face of test panel 7, an unamended adobe cap installed in 1992 on the west end of the south wall of historic Feature 16. The top course of adobes has since weathered to about 1/3 of its original height; there is little difference in erosion between the cap and the wall.

7.2 Test panel 2: 20% El Rey Superior 200, two coats

The protective coating on test panel 2 was composed of two coats of earthen render, each 3/4" thick, amended with a 20% solution of El Rey Superior 200 in water. This protective coating is in the best condition of all the test panels. In July of 1992 very little erosion was observed, while moderate erosion was observed by October 1994. Much of the material retains its smooth original finish coat and, because less erosion has taken place, less large aggregate is exposed. There is minor cracking, and the cracks tend to be fine with sharp edges. The finish coat has been lost in several patches toward the top of the wall, but in these areas the bottom coat is intact. The bottom coat exhibits good adhesion to the historic adobe, although there is minor detachment of the top coat from the bottom coat. The color of this protective coating is identical to the control. No historic adobe is exposed. The condition of the protective coatings is comparable to that of the earthen renders amended with 1:5 and 1:10 solutions of El Rey Superior 200 on the test wall panels 1S2 and 1N2.

7.3 Test panel 3: 10% and 20% Rhoplex E-330

Test panel 3 was divided in half to test two concentrations of Rhoplex E-330. The west half of the historic adobe wall was covered with two coats of earthen render, each 3/4" thick, amended with a 10% solution of Rhoplex E-330 in water. The earthen render on the east half was amended with a 20% solution of Rhoplex E-330 in water. In appearance, this panel is almost identical to test panel 6 (10% and 20% El Rey Superior 200).

By July 1992 large cracks had appeared in the protective coating, and these cracks had eroded by October 1994. The west half of the panel (10% E-330) exhibits a soft, convoluted erosion pattern in the top coat with large, more sharply-defined cracks in the bottom coat where it is exposed in several locations. In color it is identical to the control. No historic adobe is exposed. The east half of the panel (20% E-330) is well-adhered and in good condition; the top coat is almost entirely intact. Cracks are fewer than in the west half, but somewhat larger and more sharply defined. There is some erosion of the bottom coat from beneath the harder shell of the top coat, but no historic adobe is exposed. In color it is identical to the control.

7.4 Test panel 4: 10% El Rey Superior 200 and water repellent

The protective coating on test panel 4 was composed of two coats of earthen render, each 3/4" thick, amended with a 10% solution of El Rey Superior 200 in water. After drying, the render was sprayed with one gallon of undiluted El Rey Adobe Protector, a prepolymerized methyl alkoxysilane. On the south face, the condition of this protective coating is very similar to panel 2, but the water repellent has made the top coat lighter in color. Where it is exposed, the bottom coat is identical in color to the control. On the north face, the lighter coat has spalled in patches from the upper half of the wall, exposing the darker bottom coat and giving the wall a patchy appearance. In these areas the bottom coat has begun to erode from beneath the harder edges of the top coat. The bottom coat exhibits good adhesion to the historic adobe, although there is minor detachment of the top coat from the bottom coat. Minor erosion of the historic adobe has occurred at the top of the wall where the protective coating abuts panel 5.

7.5 TEST PANEL 5: WATER REPELLENT

The protective coating on test panel 5 was composed of 2.5 gallons of El Rey Adobe Protector, a prepolymerized methyl alkoxysilane, which was sprayed directly onto the historic adobe; no dusting or removal of loose material was done prior to application. In July of 1992 the water repellent layer was intact, but by October 1994 it was flaking or entirely gone from most of the panel. Presently, unsightly flakes and patches of the water repellent are still visible because they are lighter in color than the historic adobe. The water repellent appears to have had a very low depth of penetration, forming a film on the surface of the adobe. Erosion of the historic adobe is the worst on this panel; it is common around the edges of historic adobe which retain the water-repellent film.

7.6 TEST PANEL 6: 10% AND 20% EL REY SUPERIOR 200, ONE COAT

Test panel 6 was divided in half to test two concentrations of El Rey Superior Additive 200. The protective coating on the west half was composed of one coat of earthen render, 3/4” thick, amended with a 10% solution of El Rey Superior 200 in water. The earthen render on the east half was amended with a 20% solution of El Rey Superior 200 in water. In appearance, this panel is almost identical to Panel #3. Very little erosion was observed in July 1992 or in October 1994. On the west half of the panel (10% El Rey) the protective coating exhibits slightly more cracking but is otherwise identical to the west half of panel 3 (10% E-330). Preferential erosion of the historic adobe has occurred where the protective coating abuts panel 5. On the east half of the panel (20% El Rey), the protective coating is almost identical to the east half of panel 3 (20% E-330). Erosion of the historic adobe has occurred on the south face of the panel where the protective coating abuts the untreated adobe wall.

7.7 TEST 7: UNAMENDED ADOBE CAP

For test 7, a 10' long section of weathered historic adobe blocks was removed from the top of the wall and replaced with three courses of unamended adobe blocks laid in unamended earthen mortar. The three-course unamended adobe cap is in good condition, although the top course has weathered to about one-third of its original height. In 1997, no accelerated erosion of the historic adobe beneath the cap was observed on the south side of the wall, while only minor erosion was observed on the north side. By 2000, the south side of the wall had been re-rendered with unamended earth and the condition of adobes beneath the cap could not be determined. On the north side, accelerated erosion was still minor.

The color of the capping adobes is somewhat grayer and darker than the historic adobes, and runoff from the cap has stained the underlying adobe a darker color. The high ratio of aggregate in the cap makes it easily distinguishable from the historic adobe; as the fines weather out, the exposed aggregate gives the cap a very rough texture and makes it visually obtrusive.

7.8 CONCLUSIONS AND RECOMMENDATIONS

The results obtained from these test panels confirm the findings of the Adobe Test Wall Project – Phase I. The addition of 10% and 20% solutions of El Rey Superior Additive 200 is very effective in prolonging the life of earthen renders. The color and weathering pattern of the amended renders is compatible with the unamended earth. Perhaps the most significant result was that the amended renders adhered almost as well to the dusty, crumbling historic adobe as they did to the new adobe of the test walls. Earthen protective coatings, amended or not, do obscure the coursing of the adobe walls and tend to transform walls from legible architectural units into monolithic masses. This may not be acceptable to managers of the site, but it should be remembered that most, if not all, of the walls were originally rendered with lime plaster and the adobes were never meant to be exposed for both practical and aesthetic reasons.

At lower concentrations (10%), the solutions of both El Rey and E-330 tended to develop a number of fine cracks. At higher concentrations (20%), less cracking occurred but the cracks were larger and more damaging to the protective coating. Thus, if earthen renders are selected for use, the 10% solution can be recommended as an additive for larger-scale trial testing on the historic walls at Fort Selden. As well, it appears that only one coat of amended render is needed on the vertical faces of walls: after eight years of exposure the render on test panel 6, to which one coat was applied, was still in good condition. However, the use of two coats is recommended at the tops of walls where exposure is much greater. The use of the 10% solution and the application of only one coat of render to the vertical faces of the walls would reduce the time and expense involved in applying the protective coatings to historic walls.

The erosion resistance, color, texture, and weathering patterns of the El Rey and the Rhoplex E-330 were virtually identical. The defoaming agent does not appear to alter the performance of the El Rey and may make it easier to mix (although this may only be important in high-speed mixing, as for grout). However, the El Rey was very easy to apply while the E-330 tended to pull away from the adobe substrate and developed more shrinkage cracks (Guzman n.d.).

The use of the water repellent, either applied to the amended protective coatings or directly to the adobe walls, is not recommended. As with the other spray applications applied to the adobe test walls, depth of penetration was poor and a surface crust was formed, leading to accelerated erosion of the adobe once the crust was breached. As well, the water repellent made the amended and unamended earth much lighter in color, and created a patchy appearance as the crust failed and the darker render or adobe was exposed.

In contrast with the four caps tested in the Adobe Test Wall Project – Phase I, there is little difference in the rate of erosion between the earthen cap and the upper faces of the adobe wall. But the rate of loss from the upper vertical wall faces may be comparable with the rates of loss on test wall 3. It is just not as obvious because there is no datum or monitoring rod to mark the 1992 dimensions of the cap and the wall. In the absence of quantitative data collected from the beginning of installation, no definitive conclusions can be drawn about the caps and their effects on the walls.

But earthen caps do not cause any direct damage to the adobe walls, and it is recommended that unamended adobes be used if and when caps are installed at the site in the near future. Given the material composition of the adobe and the climate at Fort Selden, one course of adobe has a working life of about 8-10 years. If two courses of adobe are allowed to erode before caps are replaced, the capping maintenance cycle is 15-20 years. But further capping tests should be conducted in order to identify potential improvements to unamended caps, which have much shorter maintenance cycles at other sites. For instance, the addition of very dilute solutions (<5%) of acrylic dispersion or of low quantities of white cement might increase the working life of the adobe without appreciably altering its permeability or weathering characteristics.

8.0 OVERVIEW OF PHASE I PUBLICATIONS

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Throughout the course of the Fort Selden Adobe Test Wall Project - Phase I, four articles were published on the experimental design, methodology, and initial results of the experiments. Two of the articles were written for the general public and provided overviews of the project (Caperton and Taylor 1989, Dayton 1991). The two others were technical articles which presented the preliminary results of the project after two years and five years of exposure. These articles were written by Michael Taylor and were presented at the 5th and 6th International Conferences on the Conservation of Earthen Architecture (Taylor 1988, 1990). Copies of the articles are included in Appendix F.

8.1 "FORT SELDEN TEST WALL STATUS REPORT" (TAYLOR 1988)

The first technical article was entitled "Fort Selden Test Wall Status Report", and was presented at the 5th International Conference on the Conservation of Earthen Architecture, held in Rome, Italy, on 22-23 October, 1987 (Taylor 1988). After describing Fort Selden and the experimental design and construction of the test walls, the article presented the preliminary results of the Adobe Test Wall Project – Phase I after 22 months of exposure.

Even after only two years of exposure, the results of the protective coating experiment were very consistent with those presented in this report after fifteen years of exposure. As a group, the amended renders displayed the least erosion, and among those El Rey Superior 200 and Daraweld-C showed the greatest erosion resistance. Renders amended with Soil Seal Concentrate and asphalt emulsion also showed good erosion resistance. The 1:5 solutions displayed slightly less erosion than the 1:10 solutions, and all of the mixes darkened the unamended earth to some extent (although this was sometimes too subtle to change the Munsell reading). The agave juice and straw additives had not performed as well and displayed moderate erosion, but did not discolor the earth.

Among the spray and roll-on applications, Super Quickseal was misidentified as a spray application.[7] The spray and roll-on applications did not perform as well as the amended renders, but the two roll-ons (Acryl 60/Super Quickseal and Thorocoat) provided the best erosion resistance. The performance of these applications was summarized as follows: "It appears that, at least in this experiment, unamended mud plaster withstands erosion as well as, if not better than, the spray applications." But after fifteen years of exposure, one of the spray applications (Silicote) and both of the roll-on applications (Acryl 60/Super

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[7] The Acryl 60 subcoat was sprayed on the wall but the Super Quickseal was applied with a paint roller; this is also misreported in the project summary prepared by Gossett and Gossett (1985: 12) but is reported correctly in the daily log, which is assumed to be correct because it was written closest to the time of application (Gossett and Gossett 1985: 14).

Quickseal and Thorocoat) did perform better than the unamended earthen render in terms of erosion resistance. Issues of material compatibility, texture, and weathering patterns were not directly addressed in the article, and it is in these categories that the spray and roll-on applications do not score well.

In the wall cap experiment, no erosion was observed in the adobe beneath the stabilized, sloped, and overhanging cap (3S2 and 3N2), while erosion beneath the other three caps was comparable. Thus it was concluded that the sloped cap was the best. This proved a short-lived phenomenon, however, and after five years of exposure the sloped cap did not reduce erosion any better than the other three caps (Taylor 1990: 388). After nine years of exposure, the sloped cap had caused more erosion than the cement-based cap or the brick cap.

The results of the wall foundation experiment were quite limited due to the paucity of readings obtained from the soil cells. “With the exception of the walls which are surrounded by the concrete wainscots, virtually no data is being obtained from the sensors which are located above the ground surface” (Taylor 1985: 99). No coving was observed at the bases of the walls either. While these initial results seemed disappointing, the ultimate results of the wall foundation experiment were quite interesting. By combining the limited results from the soil cells with the long-term qualitative erosion of the walls, significant conclusions can be drawn.

To summarize, the early results obtained in the Adobe Test Wall Project were quite consistent with the results after five and fifteen years of exposure. The exceptions are the poor short-term but good long-term good performance of one spray application and the two roll-on applications in the protective coating experiment, and the good short-term but poor long-term performance of the sloped adobe block in the wall cap experiment.

8.2 “AN EVALUATION OF THE NEW MEXICO STATE MONUMENTS ADOBE TEST WALLS AT FORT SELDEN” (TAYLOR 1990)

The second technical article was entitled “An Evaluation of the New Mexico State Monuments Adobe Test Walls at Fort Selden,” and was presented at the 6th International Conference on the Conservation of Earthen Architecture, held in Las Cruces, New Mexico, on 14-19 October 1990 (Taylor 1990). After describing Fort Selden and the experimental design and construction of the test walls, the article presented the preliminary results of the Adobe Test Wall Project – Phase I after five years of exposure.

The results of the protective coating experiment after five years are similar to those after fifteen years of exposure. A comparison of erosion ratings is provided in Table 35. After fifteen years, the panel of unamended earth and those amended with agave juice and straw show some improvement in erosion resistance in comparison with two of spray applications, K & E Mineral Sealer and linseed oil, which show a comparative decrease in erosion resistance. But the same additives provide the greatest increase in erosion

Table 35. A comparison of Fort Selden protective coating erosion rankings in 1990 and 2000.

Panel	Additive	Application	Ranking	
			1990	2000
1	unamended earth	render	13	9
2	El Rey 200	render	1	1
3	Daraweld-C	render	2	2
4	asphalt emulsion	render	3	3
5	Acryl 60/Super Quickseal	roll-on	4	6
6	K&E	spray	10	12
7	linseed oil	spray	8	13
8	Thorocoat	roll-on	4	4
9	agave juice	render	12	10
10	Soil Seal Concentrate	render	4	4
11	Silicote	spray	7	7
12	Seal-Krete Sealer	spray	10	10
13	straw	render	9	8

resistance after five and fifteen years: El Rey Superior 200, Daraweld-C, and asphalt emulsion.

The article also recommends that, in the future, Rhoplex E-330 be used instead of El Rey Superior 200 to avoid discoloration of the earthen materials. But in subsequent trial tests on the historic adobe walls at Fort Selden, the E-330 proved difficult to apply and displayed poorer adhesion and greater shrinkage cracking than the El Rey (see Section 7.8). Thus the use of El Rey Superior 200 is recommended over E-330 in this report. All other observations in the 1990 article are consistent with those made in this report.

9.0 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH AND APPLICATION

> The fact that no "final solution" is or will be available for the adobe conservation problem is never stressed enough. This is true for all materials, but particularly so for adobe, whose weak characteristics have always been counteracted with regular maintenance and extensive rebuilding. The fact that modern conservators obviously cannot act with the same freedom in rebuilding damaged parts of historic buildings, simply means that, on the long range, they are condemned. All we can hope for is to enhance their life expectancy (Chiari 1983: 37).

The Fort Selden Adobe Test Wall Project – Phase I has provided valuable insight into the preservation of earthen architecture through the use of protective coatings, caps, and wall foundation treatments. The results of the project are of course specific to the soils and site conditions of Fort Selden. The conclusions of the three major experiments in the Adobe Test Wall Project are summarized below; discussions of their applicability to other earthen sites and recommendations for future research are also included.

9.1 PROTECTIVE COATINGS

Test walls 1 and 2 of the Adobe Test Wall Project – Phase I were exposed to the extreme climate of southern New Mexico for fifteen years. The data collected during that time provides definitive results on the qualitative weathering characteristics of thirteen protective coatings tested on those walls, including color matching and stability, erosion resistance, material compatibility, texture, and weathering patterns. Several amended renders were identified which can reduce the frequency of maintenance without significantly compromising the adobe walls. But no compatible spray or roll-on coatings were identified which would eliminate the need for a render and allow the adobe coursing to remain visible.

Of the thirteen protective coatings applied to test walls 1 and 2, the earthen renders amended with 1:5 and 1:10 solutions of El Rey Superior Additive 200 displayed the best overall performance. The color of the panels was similar or identical to that of unamended earth and remained relatively stable over time. The panels possessed a good initial texture, displayed the best erosion resistance over time, and eroded in a pattern similar to that of unamended earth. Material compatibility with the adobe wall was also adequate. Also in its favor, El Rey Superior 200 is relatively inexpensive (an additional $2.42/m^2 above the cost of the soil if the render is one inch thick), non-toxic, and easy to use. Another important consideration is that, because the additive is contained in the new protective coating, the composition of the historic material is not altered. Based upon these results, if amended earthen renders are selected for use on the historic walls at Fort Selden, El Rey Superior 200 can be recommended as an additive for larger-scale trial testing in order to further evaluate its effectiveness at protecting the historic adobe walls and reducing the frequency of maintenance. El Rey Superior 200 can also be recommended as a potential additive to earthen renders used in contemporary construction; its performance would be further improved if the walls were raised on foundations and roofed.

The material characteristics of El Rey Superior 200 and its interaction with a variety of earthen materials have been well-studied. As well, it has been field tested at a number of sites, almost always with good results. But it should be noted that

> the soils impart the major properties to an acrylic-modified [earth] – not the other way around. An acrylic emulsion used in proportions of up to 33% in water cannot overwhelm the natural characteristics of a soil. Porous and permeable sandy soils remain porous and permeable. Active fine-grained soils continue to shrink and swell. This is a critical and important factor in understanding the relationship among soil types, [the acrylic emulsion], and their performance (Hartzler 1996: 54).

Thus El Rey Superior 200 can be recommended for application at sites with soils and environmental conditions similar to Fort Selden, and for trial application at sites with dissimilar soils and environments.

Three other panels showed a significant increase in erosion resistance when compared with the unamended earthen render, and were mostly compatible in terms of color, material characteristics, texture, and weathering patterns. These were panels 3 (Daraweld-C), 4 (asphalt emulsion), and 10 (Soil Seal Concentrate). Four of the protective coatings did not provide any improvement over unamended earthen render and are not recommended for use, at least not as they were used at Fort Selden. These were panels 6 (K & E Mineral Sealer), 7 (linseed oil), 9 (agave juice), 12 (Seal-Krete), and 13 (straw). Three protective coatings did show marked improvement over unamended earthen render, although their material characteristics, textures and erosion patterns were not compatible with the adobe wall; these were panels 5 (Acryl 60/Super Quickseal), 8 (Thorocoat), and 11 (Silicote). In a wetter environment, further research on all of the protective coatings would be required to determine the effects of the reduction in permeability and water vapor transmission on the underlying adobe wall.

While many of the protective coatings are not appropriate for use as long-term coverings for standing adobe walls, a few might have other applications. For instance, Thorocoat adhered well to unamended earthen render, provided excellent erosion resistance over a short period of time, and was easy to peel away from the unamended adobe and render. In combination with an intermediate layer of unamended earthen render, it might be used for temporary protection of archaeological excavations (Taylor, personal communication).

The thirteen protective coatings tested in the Adobe Test Wall Project – Phase I are only the tip of the iceberg. A vast number of protective coatings for earthen architecture have been proposed over the years, and a few have been tested. Different methods of preparing and applying the protective coatings compound the potential number of treatments. Thus a wide range of additional research projects could be designed to test other protective coatings and/or different application parameters.

Other protective coating materials might include new or improved chemical products which have been adapted and tested in the laboratory for their appropriateness for use on adobe, as was done for the Fort Selden Test Wall Project - Phases II and III, and proprietary products specifically designed for use on adobe. Traditional materials which have been used in many parts of the world, like lime, caliche, hydraulic lime, pozzolans, and organic additives (other cactus juices or mucilages, urine, manure, casein, egg albumin termite saliva, banana, charcoal, etc.), deserve more investigation and research under controlled conditions. These locally occurring materials are often readily available and less expensive than synthetic or proprietary products. And other synthetic and organic fibers (in place of straw) might be researched that would help to reduce shrinkage cracking and improve the strength and abrasion resistance of earthen materials. To supplement the field testing, laboratory research into the chemical, physical, and mechanical properties of the additives, both synthetic and organic, and their interactions with the soils would help to pinpoint why certain products work and others do not.

Different preparation and application parameters could also be tested, including variations in slaking or wetting time of the additive or amended soil; preparation and pre-wetting of the substrate; conditions of cure (humidity, temperature, duration); application techniques (smooth troweling, rough troweling, hand application, sponge application); and so forth. The variables to be tested would be dependent on the properties of the additive. Intensive monitoring of the microclimate in and adjacent to each test panel would provide insight at application and throughout the process of deterioration.

Accelerated deterioration of the wall tops is a result of their increased exposure to wind, rain, accumulations of snow, and wide ranges of temperature. Combinations of materials could be tested which incorporated the use of a stronger material at the wall cap and a weaker material (which would probably be more materially compatible) on the wall faces. Different materials could also be used at the wall bases where accelerated erosion is a problem, and on vertical wall faces which are more exposed to the weather (e.g., on west and north wall faces at Fort Selden).

Experiments with soil compositions could also be conducted. The general parameters of particle size distribution for a good adobe (50-75% sand and 9-28% clay) are well understood, but slightly different soil compositions may perform better with specific additives. For instance, certain acrylic emulsions perform best in soils with at least 60-65% coarse sand and 10-15% clay (Hartzler 1996: 53). However, it is difficult to control soils obtained from natural sources and testing of each wheelbarrow-full or even truckload would become expensive. Good control could only be obtained by entirely manufacturing a soil from sands, silts, and clays of known and uniform composition. Again, this would be expensive and perhaps not useful or practical for regular use at many sites.

The Adobe Test Wall Project – Phase I and other experiments indicate that the maximum useful life of an unmaintained amended protective coating is about 10 years. At some sites, this may be too small a gain to warrant the cost and the potential change in the physical, mechanical and chemical properties of the original walls. Further research into monitoring and maintenance programs would provide valuable information to site managers on the long-term performance and cost effectiveness of amended protective coatings.

9.2 WALL CAPS

Test wall 3 was designed to assess the relative effectiveness of four caps at protecting the underlying adobe wall and to determine if they reduced or accelerated erosion in comparison with uncapped walls. The results illustrate that caps do reduce erosion from wall tops: after fifteen years of exposure, all of the capped walls (prior to collapse) were 100% of their original height while an uncapped control had lost 23% of its original height. It is still uncertain, however, to what extent caps might accelerate erosion of unamended adobe walls. Because the upper vertical faces of walls are more exposed, they naturally lose more material than the lower vertical wall faces on both capped and uncapped walls. Given the lack of data from the early years of the experiment when the rates of erosion from the vertical faces of uncapped and capped walls could be most accurately compared, it is not possible to distinguish between natural erosion and any accelerated erosion which may be caused by the caps.

But among the caps on test wall 3, it can be stated that the vertical faces of adobe walls beneath brick and cement-based caps displayed the least erosion (and perhaps less than an uncapped wall), while the asphalt stabilized and sloped adobe cap showed initial promise but the underlying wall faces eventually displayed the greatest erosion (perhaps as much or more than an uncapped wall). Unamended adobe caps which were applied to the historic walls in 1992 are eroding at the same rate as the adobe walls, and rates of erosion from the upper vertical wall faces may in fact be comparable to the rates beneath the caps of test wall 3. But until more definitive results are obtained, unamended earthen caps are recommended for use at Fort Selden.

It would be very helpful separate the effects of natural erosion on upper wall faces from the effects of any accelerated erosion which may be caused by caps. This might be done by designing an experiment which quantified, at frequent time intervals, the rates of erosion in walls capped with materials of varying hardness and permeability, and uncapped controls. Potential additives include all of those discussed for protective coatings as well as the inclusion of straw mats, fiber mats, or gravel between adobe courses and on top of the wall to increase erosion resistance.

After the effects of natural and accelerated erosion are separated, it would be useful to pinpoint the exact processes by which some caps cause accelerated erosion of adobe walls. An intensive study of an unamended control cap, caps which were proven to cause accelerated erosion, and the underlying adobe walls could be conducted which would collect information on temperature, relative humidity, moisture content, soluble salt content, permeability, porosity, and so forth, allowing for insight into this phenomenon. Also, the installation of monitoring rods in the unamended adobe would provide more data on the location and rate of erosion through time and facilitate comparisons between different types of caps.

Once the causes of accelerated erosion have been pinpointed, directed research into alternative capping materials and designs could be conducted in order to develop a durable cap which protects the wall top but does not cause accelerated erosion. In terms of design, the sloped and overhanging cap tested at Fort Selden showed initial promise. Further refinement of the design might include the installation of a bead or other drip edge on the bottom edge of a flat or slanted overhanging cap, which would prevent moisture from moving back along the underside of the cap and reaching the wall. But while overhanging caps do show the most promise, they have aesthetic and practical flaws. They significantly alter the appearance of the wall; this visual disruption is exacerbated in strong light, when the cap casts a shadow on the wall top. They are also difficult to install on stepped or rounded walls.

The permutations of capping materials and designs are endless. To limit the variables and ensure applicable results, the design of future research projects should be guided by issues of cost, repeatability, ease of installation, and aesthetics.

9.3 WALL FOUNDATIONS

Test walls 4 through 15 were used to test the relative effectiveness of twelve different wall foundations at reducing capillary rise in adobe walls, thereby reducing the effects of basal erosion. In the wall foundation experiment, two test walls displayed little or no basal erosion after fifteen years of exposure and no moisture retention above grade: the adobe wall with a stone foundation and the adobe wall with an adobe foundation and French drains on either side. Both of these foundation types have been and continue to be commonly used in adobe construction with few adverse impacts on adobe walls.

Based upon the results of the test wall experiment, it is important that stone foundations at Fort Selden and at similar earthen sites be maintained and kept clear of soil deposits and debris. When the stone foundations are buried, the walls are essentially left with adobe foundations; this foundation type was the first to collapse in the test wall project. But many historic walls are constructed on adobe foundations. The project results indicate that moisture can be reduced in these walls by installing French drains, thus reducing basal erosion and prolonging the life of the wall.

The limited results obtained with the thermistor soil cells were a disappointment. Electrical resistivity methods like those used for this project are good for measuring mid-range moisture contents; however, they do not perform well at very low moisture contents. In any future wall foundation experiments, resistivity cells might be used in combination with artificial flooding to obtain quick, measurable results.

Other non-destructive methods for directly measuring low moisture content include capacitance methods which measure the dielectric constant of soil, which in turn is greatly affected by water content. An example of this is time domain reflectometry, which

> operates on the principle of microwave-pulse travel through a parallel transmission line (the probe). This technology was adapted from the electric power industry, where cable testers are used to determine the location of a break in a power line. The speed of the microwave pulse depends on the dielectric constant K of the medium that surrounds and is in contact with the probe [three parallel transmission lines constructed with stainless steel rods that are of equal length]. Because of the significant difference between the dielectric constant of water and those of other constituents in soils, the speed of the pulse down the probe is highly dependent on soil-water content (Tindall and Kunkel 1999: 565; see also Kutílek and Nielsen 1994: 35-37).

Another method is the surface neutron probe (used to detect leaks in roofs and adapted by the agricultural industry to measure surface soil moisture), which utilizes a source of fast neutrons that lose energy (are slowed down) when they interact with the soil; higher energy loss is directly related to higher water content (Farah et al. 1984: 235, Kutílek and Nielsen 1994: 39-43).

> The neutron probe works on the principle of neutron thermalization. It determines water content by releasing high-energy ("fast") neutrons from a radioactive source… The high-energy neutrons collide with hydrogen atoms in the soil, and form what are known as thermal neutrons. The multiple collisions that take place form a thermal cloud of neutrons whose size is constant, but whose density is dependent on soil-water content. Higher water content leads to increased thermalization and, thus, denser thermal clouds. A "slow" neutron detector, installed adjacent to the source emitter, measures the cloud. The measurement is displayed in the form of a "count ratio," with a higher count denoting a higher water content (Tindall and Kunkel 1999: 565).

A third method to directly measure soil moisture is through the use of calcium carbide. With this method, a standard weight of soil is mixed with a standard amount of calcium carbide, inserted in a pressure chamber, and shaken. Steel balls in the chamber pulverize the soil and the carbide reacts with the moisture in the soil to form acetylene gas. The pressure of the gas, read on a meter attached to the chamber, is then related to the moisture content of the soil. This is an ASTM standard method for measuring soil moisture, but it does require destructive sampling for each reading and is probably not useful for test walls.

Other methods are available which indirectly measure soil water pressure, which is then related to moisture content through the use of a soil water retention curve. One method is the heat dissipation method, which puts out a pulse of heat and measures its dissipation (a function of the thermal conductivity of the soil, which is linearly related to the soil water pressure). Another method uses psychrometers to measure the relative humidity of the soil. These two methods are probably not useful for adobe test walls because at each location where moisture content is to be measured, an intact soil core must be taken. With the core, soil moisture is related to soil water potential by creating a soil water retention curve in the laboratory. Soil water retention curves are directly affected by specific pore size and geometry, thus an intact core is necessary.

In the future, it would be very interesting to use the good results of the protective coating experiment and the wall foundation experiment to design a new research project. The chief objection to the use of amended protective coatings is that they may trap moisture in the underlying adobe wall. Test walls could be constructed on both adobe and stone foundations and then rendered with unamended earthen protective coatings, earthen protective coatings amended with acrylic (El Rey Superior 200), vinyl acetate (Daraweld-C) and asphalt emulsion, cement, and other potential additives (e.g., lime, hydraulic lime, and traditional organic materials). The walls could be artificially flooded and moisture levels monitored through time in order to determine the impact of the more successful protective coating treatments on the moisture content of adobe walls.

It might also be useful to simulate unsaturated water transport through the adobe using numerical models. Water migration pathways could be delineated and the spatial distribution of soil moisture could be estimated; the effects different foundations and protective coatings have on the transport of liquid could then be assessed. However, most models that are used to simulate unsaturated water transport (e.g., HYDRUS-2D) neglect vapor transport, which is a reasonable assumption for fairly moist conditions but may be a poor assumption and yield less accurate results for drier conditions like those at Fort Selden, where vapor transport may be dominant. This is important because the inhibition of vapor transport and resultant accumulation of liquid behind foundation treatments or protective coatings may cause the most damage to the walls. As well, it is likely that obtaining values for parameters and boundary conditions used in the models would be quite difficult or would require additional data collection. Instead, generic parameter values could be estimated, entered in the model, and then used to assess the effects that various treatments may have on the general transport patterns of liquid water and the distribution of moisture within the wall.

No further testing or analysis of the adobe test walls is recommended. However, the monitoring data would be more complete if the remaining walls were photographed once a year until complete failure. More might be learned about the remaining wall foundation treatments in particular.

At any earthen site, the selection of a preservation treatment should be the result of careful study of the environmental conditions and the physical, mechanical, and chemical properties of the materials used in the architecture, as well as the properties of potential repair materials drawn from both traditional and modern sources. All of this information should be filtered through the preservation philosophy and practical considerations of the persons or agency managing the site (e.g., no loss is acceptable, some loss is acceptable, only traditional materials should be used, funding is extremely limited, the site is very remote, the site is heavily visited, etc.), after which a number of preservation materials or methods can be selected for testing. The experimental design and methodology used for the Fort Selden Test Wall Project – Phase I are simple and straightforward, and should provide site managers with the information necessary to design a research project, evaluate the results, and select an appropriate protective coating, cap, or wall foundation treatment.

BIBLIOGRAPHY

Agnew, Neville. 1987. "Adobe preservation. Report on a three month research project the Getty Conservation Institute." Unpublished report, March 1987. Santa Fe: Museum of New Mexico State Monuments archives.

Agnew, Neville. 1990. "The Getty adobe research project at Fort Selden I. Experimental design for a test wall project." In **6th International Conference on the Conservation of Earthen Architecture, Adobe 90 Preprints** (Las Cruces, New Mexico, USA, October 14-19, 1990), 243-249. Los Angeles: The Getty Conservation Institute.

Agnew, Neville, Frank Preusser and James R. Druzik. 1988. "Strategies for adobe preservation." In **5th International Meeting of Experts on the Conservation of Earthen Architecture** (Rome, 22-23 October 1987), 3-12. Grenoble: ICCROM/CRATerre-EAG.

Beas, Maria Isabel. 1991. "Traditional architectural renders on earthen surfaces." Master's thesis, Graduate Program in Historic Preservation, University of Pennsylvania.

Bleick, Ed (K&E Chemical Company). 2000. Personal communication to author, 19 June 2000.

Bulloch, H. Edward Jr. and Raymond E. Neher. 1980. **Soil Survey of Dona Ana County Area, New Mexico.** United States Department of Agriculture, Soil Conservation Service, in cooperation with United States Department of the Interior, Bureau of Land Management, New Mexico Agricultural Experiment Station.

Caperton, Thomas. 1984. Memorandum to Sen. Lamar Gwaltney, 26 January 1984, re: "Stabilization and structural monitoring: Fort Selden State Monument, Radium Springs, New Mexico." Santa Fe: Museum of New Mexico State Monuments archives.

Caperton, Thomas J. 1993. "Long term preservation issues related to earthen archeological sites." In **7th International Conference on the Study and Conservation of Earthen Architecture** (Silves, Portugal, October 24 to 29, 1993). Lisbon: Direcção Geral dos Edifícios e Monumentos Nacionais.

Caperton, Thomas J. and Michael R. Taylor. 1989. "The great adobe experiment." **El Palacio** 95, no. 1, 70-74.

Carmichael, D. 1987. Letter to Neville Agnew, 30 July 1987. Santa Fe: Museum of New Mexico State Monuments archives.

Chiari, Giacomo. 1983. "Characterization of adobe as building material: preservation techniques." In **Adobe: International Symposium and Training Workshop on the Conservation of Adobe** (Lima-Cusco, Peru, 10-22 September 1983), 31-40. Rome: UNDP/UNESCO/ICCROM.

Coffman, Richard, Charles Selwitz and Neville Agnew. 1990. "The Getty adobe research project at Fort Selden II. A study of the interaction of chemical consolidants with adobe and adobe constituents." In **6th International Conference on the Conservation of Earthen Architecture, Adobe 90 Preprints** (Las Cruces, New Mexico, USA, October 14-19, 1990), 250-254. Los Angeles: The Getty Conservation Institute.

Cohrs, Timothy and Thomas J. Caperton. 1974. **Fort Selden, New Mexico.** Santa Fe: Museum of New Mexico Monuments Bureau.

Crocker, Edward and M. Susan Barger. 1993. "Report on the behavior of certain adobe mixes with modern polymer and natural amendments for use as capping materials at archeological sites." Unpublished report, April 1993. Santa Fe: Museum of New Mexico State Monuments archives.

Dayton, Leigh. 1991. "Saving mud monuments." **New Scientist** 25 May 1991, 38-42.

Farah, S. M., R. J. Reginato and F. S. Nakayama. 1984. "Calibration of soil surface neutron moisture meter." **Soil Science** 138, no.3: 235-239.

Fenn, Dennis B. and Elvia E. Niebla. 1981. "Mud plaster preservation research, Bent's Old Fort National Historic Site, National Park Service, 1981." Unpublished report. Santa Fe: National Park Service archives.

________. 1991a. "Fort Selden test wall project. November 1985 – June 1991. 1N1 wall – 1N13 wall." Black and white prints. Santa Fe: Museum of New Mexico State Monument archives.

________. 1991b. "Fort Selden test wall project. November 1985 – June 1991. 1S1 wall – 1S13 wall." Black and white prints. Santa Fe: Museum of New Mexico State Monument archives.

________. 1991c. "Fort Selden test wall project. November 1985 – June 1991. 2E1 wall – 2E13 wall." Black and white prints. Santa Fe: Museum of New Mexico State Monument archives.

________. 1991d. "Fort Selden test wall project. November 1985 – June 1991. 2W1 wall – 2W13 wall." Black and white prints. Santa Fe: Museum of New Mexico State Monument archives.

________. 1991e. "Fort Selden test wall project. November 1985 – June 1991. 3S1 wall – 3S4 wall." Black and white prints. Santa Fe: Museum of New Mexico State Monument archives.

________. 1991f. "Fort Selden test wall project. November 1985 – June 1991. 3N1 wall – 3N4 wall." Black and white prints. Santa Fe: Museum of New Mexico State Monument archives.

________. 1991g. "Fort Selden test wall project. November 1985 – June 1991. TW 4–15 south face, TW 4–15 north face." Black and white prints. Santa Fe: Museum of New Mexico State Monument archives.

Gossett, William J. 1986. "Proposal for addition of a third plaster coat on the test walls at Fort Selden [sic] State Monument; for preparing an additional test wall panel with agave as an amender; and for installation of dial switches at the test wall moisture monitors." Unpublished proposal, Rio Abajo Archaeological Services, Polvadera, NM. Santa Fe: Museum of New Mexico State Monuments archives.

Gossett, William J. and Cye W. Gossett. 1985. "Test wall construction narrative, Fort Selden State Monument." Unpublished report, Rio Abajo Archaeological Services, Polvadera, NM. Santa Fe: Museum of New Mexico State Monuments archives.

Guzman, José. n.d. "Fort Selden State Monument 1991, 1992 Stabilization Project." Unpublished report. Radium Springs, New Mexico: Fort Selden State Monument files.

Hartzler, Robert. 1996. **Acrylic-Modified Earthen Mortar.** Intermountain Cultural Resource Center, Professional Paper no. 61. Santa Fe: Intermountain Cultural Resource Center.

Horie, C.V. 1987. **Materials for Conservation**. London: Butterworths.

Kutílek, Miroslav and Donald R. Nielsen. 1994. **Soil Hydrology.** Cremilingen-Destedt, Germany: Catena Verlag.

McHenry, Paul Graham Jr. N.d. “Specifications for adobe research project, Fort Selden State Monument, New Mexico.” Unpublished document. Santa Fe: Museum of New Mexico State Monuments archives.

Museum of New Mexico. 1971. "Fort Selden, New Mexico: maps, descriptions, and sources." Unpublished report. Radium Springs, New Mexico: Fort Selden State Monument archives.

Neumann, Julio Vargas, Ernesto A. Heredia Zavoni and Juan J. Bariola Bernales. 1987. “Preservation of adobe constructions in rainy areas.” In **5th International Meeting of Experts on the Conservation of Earthen Architecture** (Rome, 22-23 October 1987). Grenoble: ICCROM/CRATerre-EAG.

Oliver, Anne and Robert Hartzler. 1997. “A place in history: Fort Selden, New Mexico. Preservation plan for Fort Selden State Monument, New Mexico, first phase.” Unpublished report. Santa Fe: Museum of New Mexico State Monuments archives.

Selwitz, Charles, Richard Coffman and Neville Agnew. “The Getty adobe research project at Fort Selden III: an evaluation of the application of chemical consolidants to test walls.” In **6th International Conference on the Conservation of Earthen Architecture, Adobe 90 Preprints** (Las Cruces, New Mexico, USA, October 14-19, 1990), 255-260. Los Angeles: The Getty Conservation Institute.

________. 1985-1988. “Soil moisture meters.” File folder. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael. N.d. Weather Station Info file. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael. 1985. “Specifications for the Fort Selden stabilization and test wall project.” Unpublished document, May 1985. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael. 1986a. “Fort Selden stabilization and test wall project, 1/25/86.” VHS videotape. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael. 1986b. “Fort Selden test wall project, March 21 and 22 1986.” VHS videotape. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael R. 1986c. “Fort Selden test wall status report.” Unpublished report, November 1986. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael. 1986d. “Fort Selden test walls 1 year status documentation, 11/28/86.” VHS videotape. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael. 1987a. “Fort Selden test walls, 7/30/87.” VHS videotape. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael. 1994. Field notes in spiral notebook labeled “Tsping”. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael Romero. 1987b. "Fort Selden test wall project second annual status report." Unpublished report, November 1987. Santa Fe: Museum of New Mexico State Monuments archives.

Taylor, Michael Romero. 1988. "Fort Selden test wall status report." In **5th International Meeting of Experts on the Conservation of Earthen Architecture** (Rome, 22-23 October 1987), 91-102. Grenoble: ICCROM/CRATerre-EAG.

Taylor, Michael Romero. 1990. "An evaluation of the New Mexico State Monuments adobe test walls at Fort Selden." In **6th International Conference on the Conservation of Earthen Architecture, Adobe 90 Preprints** (Las Cruces, New Mexico, USA, October 14-19, 1990), 383-389. Los Angeles: The Getty Conservation Institute.

Teutonico, Jeanne Marie. 1988. **A Laboratory Manual for Architectural Conservators.** Rome: ICCROM.

Tindall, James A. and James R. Kunkel. 1999. **Unsaturated Zone Hydrology for Scientists and Engineers.** Upper Saddle River, New Jersey: Prentice Hall.

Ulis, Dot. 1983. Letter to Michael Taylor, 6 April 1983. Santa Fe: Museum of New Mexico State Monuments archives.

________. 1985-1990. "Weather station info." File folder. Santa Fe: Museum of New Mexico State Monuments archives.

Wilson, John P. and Thomas J. Caperton. 1977. "Fort Selden development project phase II, archeological investigations (also titled "Archeological Investigations at Fort Selden, New Mexico, 1974-1976"), Project No. 35-73-00029." Unpublished report. Santa Fe: Museum of New Mexico State Monuments archives.