CONSERVATION OF PAINTED LIME PLASTER ON MUD BRICK WALLS AT TUMACACORI NATIONAL MONUMENT, U.S.A.

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SUMMARY

The presenvation of painted lime plaster at a Spanish Colonial Mission Complex site in the southwestern United States has been a high preservation priority of the United States National Park Service. A monitoring system has isolated the principal factors involved in the cause-effect deterioration relationship and many problems have been solved. Solutions for the major remaining problem, the lack of bonding between the lime plaster and the mud brick walls have been investigated, but no obvious answer has emerged. The most promising are flexible epoxy pins that would replace the effects of plaster keys used originally.

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INTRODUCTION

The United States National Park Service began an extensive preservation program at Tumacacori National Monument to determine the causes of the continuing deterioration of an important mud brick Christian Mission complex established in what was Spanish Colonial Mexico.

The historical resource, San Jose de Tumacacori, was founded in 1691 by Padre Eusebio Francisco Kino in the northern part of New Spain known as the Pimeria Alta, an area that includes the Mexican State of Sonora as well as the southern portion of the state of Arizona, U.S.A.

In 1767 the Jesuits were expelled from the New World and the Franciscan Order was placed in charge of this mission area. The Franciscans probably utilized the existing Jesuit structures at Tumacacori until the last years of the 18th century. By ca. 1790 they had begun work on new adobe buildings and had undertaken a major alteration of the existing structures at the same location. Construction continued intermittently on this complex until about 1827 when the recently established country of Mexico ordered the expulsion of all Spaniards from Mexican lands. The church was never completed, and the associated village was finally abandoned by the indigenous people in 1848 (Figure 1) (Kessell, 1976, p. 308).

The mission in ca. 1820 consisted of a complex of church, convento, cemetery, indigenous housing and working areas, a water system, orchards, and numerous fields which undoubtedly stretched for miles. There were approximately 75 rooms in this complex of which only the church, three rooms of the convento, and a small chapel in the cemetery exist above grade today. The church was originally cruciform in plan but the transepts were closed by 1820 resulting in a single nave church whose interior dimensions are approximately 31 meters long, 6 meters wide, with a flat roof 8 meters above the nave floor. A dome and vault constructed of low fired brick that vary in size span the Sanctuary on the church, respectively. The walls of the church are nearly 2 meters thick, although the normal wall thickness of the other structures is either 0.6 meters or 1.2 meters. The mud bricks used for the construction are 30 centimeters wide, 6 centimeters thick and 60 centimeters long and were formed in wood molds.

The procedure for finishing the church was the application of two coats of lime plaster directly to adobe walls and to the fired bricks of the domes and vault. Lime wash or slips, were applied over the finish plaster, both on the interior and portions of the exterior. The

paint was then applied to the dry wash. On the interior the paint was applied primarily as a mineral pigment in an aqueous solution on a dry gypsum wash. The gypsum wash was applied on the second of two coats of lime plaster, which covered the adobes of the walls and the fired bricks of the dome. During the restoration work in the first half of the twentieth century most of the exterior lime plaster was replaced with a portland type cement stucco.

Between the mid-nineteenth century and the first years of the twentieth century, the complex suffered a great deal of deterioration from weathering and vandalism. In 1908, the site was declared a National Monument and placed under the protection of the United States Forest Service, but it was not until 1918 when an employee from the U.S. Department of Interior, National Park Service, was assigned to the site that deliberate destruction was finally brought to a halt.

When the present preservation project got underway in the fall of 1975, there were many specific questions that could not be answered, but whose resolution was necessary to insure that any preservation action would be beneficial rather than deleterious. For example, did the deterioration that could be seen on some wall surfaces extend significantly deeper into the walls? The extensive amount of stabilization work completed over the past 60 years was affecting the structure, but what was the extent of the adverse effect? Were the structural cracks in the dome still active or simply stress adjustments that occurred soon after the building was constructed?

Another obvious problem and the one dealt with in depth here was the loss of the paint in the Sanctuary of the church as it flacked off and fell to the floor. The paint in the Sanctuary is all that is visible of a much more extensive decorative scheme; consequently its preservation was of a high priority (Figure 2). However, it was simply not feasible to begin any extensive conservation work before knowing the actual conditions that led to the loss of the paint. A related problem that has proved more difficult to solve is the loss of the integrity of the bond between the lime plaster ground to the mud brick walls.

Because of the wide range and complexity of the preservation problems, the need for a well designed system to gather pertinent information was recognized early. Consequently, the monitoring system in use began by utilizing a combination of some methods and devices that had been used to monitor building conditions previously at other sites, and other methods and devices which had not been used before. Some of the methods are extremely simple, such as photographing specific decorative features on a schedule. Some devices, such as hygrothermographs and psychorometers used to measure ambient temperature and humidity had been designed specifically for that job and were readily available. Still other devices, such as electronic crack monitoring gages and internal wall moisture sensors, had been designed to meet other than preservation monitoring needs but were adapted to the problems at Tumacacori (Crosby, 1978).

HISTORY OF CONSERVATION WORK

Early stabilization work in the 1920's and 1930's consisted of filling holes in the plaster with cement, rebuilding small architectural elements such as moldings, and giving support to rough plaster edges. These stabilization attempts do provide some information about the rate of deterioration since approximate dates for most of this work is known. However, the best bench mark was the extensive work done by R. J. Gettens and Charles R. Steen in 1949. Their investigation and evaluation was thorough and the work resulting from the research is accurately described (Steen, 1962).

The work by Gettens and Steen consisted of cleaning and stabilizing painted surfaces and supporting loose plaster with a PVA solution. Many of these treated areas can be identified by a highly reflective sheen. Other areas which were treated do not exhibit the same sheen, and until recently it was thought that in these areas the "solution" had simply disappeared.

A recent evaluation of this work has clarified the knowledge of both the techniques of application and the performance of the PVA. The application, as described, was accomplished with a spray technique that often resulted in incomplete coverage. In some of the areas where the plaster wash or paint was covered by the PVA, penetration was not achieved and the adhesive material remained only on the surface. In other areas, particularly on the interior surface of the Sanctuary's dome, the PVA penetrated through the first layer of paint only to concentrate on the surface of the next layer. On other areas of high soluble salt concentrations the PVA remains only as a thin, extremely friable film that often hangs down like a thin net from the plaster surface (Figure 3).

After the time of the work by Gettens and Steen, more deterioration took place. Dust accumulated on all horizontal or vertical surfaces to some degree. Plaster continued to become friable and fall from the dome. Efflorescence occurred over large areas, especially in the northwest corner, the north, and the west side of the dome. Paint continued to flake off of the plaster base and fall to the floor.

A critical situation developed which resulted in the accelerated loss of a section of original painted plaster located in the Sanctuary of the church at Tumacacori. The specific area affected is the northwest pendentive. It was investigated by a conservator, Walter Nitkiewicz, of the National Park Service's Harpers Ferry Center in March, 1976, and it was noted that a loss of approximately ten percent of the paint had occurred up to that time. There was some additional loss of perhaps another five percent until January of 1977 when the rate of deterioration accelerated tremendously resulting in a loss of another 35 percent by the first of March, 1977 (Crosby, 1976).

January, 1977 was an extremely wet month at Tumacacori. Later information showed that the accelerated deterioration could be traced to rainfall percolating down and surfacing at the affected spot.

The affected area was examined by the project architect, another National Park Service architect familiar with conservation techniques of painted surfaces, and a private conservator. The recommendations of each of these professionals, as well as the Harpers Ferry Center conservator who examined the painted walls in 1976 was to remove the remaining paint film from the plaster of the pendentive. It was felt that the determination of the exact causes of deterioration could not be made in time to preserve the paint <u>in situ</u> and the removal of the paint film was the only possible way to save it.

An attempt was made to reattach a few square inches of paint by Mr. Nitkiewicz in March of 1976. This was done in an area where the paint had lost its adhesion to the plaster (Figure 4). The treatment was not successful as the paint in the treated area soon became detached. This was the result of a significant amount of moisture moving through the plaster from the interior of the wall.

The actual removal of the paint film was carried out by a conservator, Gloria Fraser Giffords, using the <u>strappo</u> method. The friable paint film was first stabilized with a diluted solution of a polyvinyl acetate, AYAF. A facing of cheesecloth and muslin was then attached to the paint film and removed, taking the film with it. Because of the extremely friable nature of the paint, some loss occurred both during the initial preparation and the actual removal. However, the removal of the film was considered successful and the film itself was later attached to a fiberglass backing as a permanent method of support (Giffords 1977,1979).

EXISTING CONDITIONS

<u>Paint</u>

Flaking paint that occurs without an accompanying deterioration of the plaster ground was limited primarily to the area around the northwest pendentive, above the cornice on the west side of the dome, and a small area over the transverse arch between the Sanctuary and the nave. The paint film is thin and after it pulled away from the plaster, even a slight breeze would cause it to fall to the floor. Efflorescence that formed on the plaster in much of these same areas, often pushed the paint film away from the wall (Figure 5).

Some paint deteriorated as soluble salts accumulated within the paint film literally tearing the film apart. In these situations, the film contained as much as 75% soluble salt in weight.

The source of the problem of course was moisture. Moisture migrated through the dome transporting soluable salts which recrystallized in the form of efflorescence and subflorescence. In the case of efflorescence, the salts recrystallized on the surface of the plaster, forcing the paint film away from the wall. In the case of subflorescence, the salts recrystallized in the plaster, creating pressures which fractured the plaster causing it to simply fall as it became friable. The recrystallized salts also acted hygroscopically resulting in more ambient moisture being drawn to the area of salt concentration. During the time of the accelerated loss of paint from the northwest pendentive, heavy efflorescence would reappear in a small cleaned area in only two or three days. The efflorescence appeared as recrystallized salts with chloride and nitrate anions.

Over fifty samples of efflorescence and subflorescence from the dome were evaluated for the type of anionic salts. These samples were taken from areas where various conditions existed. In some areas the sample developed on the surface of the paint film; on others, the sampled salt had actually forced the paint film from the plaster. In still other areas, the salts were occurring as subflorescence in the plaster. An ultra-violet light was also used to evaluate the efflorescence and proved valuable in further delineating areas not readily visible under natural light conditions. Under the ultra-violet light some of the efflorescence appeared flourescent and some did not. Samples were taken to try to further evaluate if these differences were significant.

Comparing the results of the salt evaluations led to no significant new theories as to the actual causes of deterioration. A large amount of nitrates appearing at this elevation in the dome (approximately 8 meters above the exterior grade) prompted a consideration of the effects that an electrical potential difference could have on increasing the vertical capillary flow in the mud brick walls. This is based on the fact that an electrical current flowing in the opposite direction of the capillary moisture movement will increase the force of the capillary suction. The electrical current can be produced by an external power supply or in the wall by the chemical reactions of various minerals desolved in the water.

Tests were conducted in an attempt to determine the electrical potential difference from the lower to the higher portions of the wall. The results, while not totally conclusive, indicated that while electrical potential differences did exist, they probably had as much effect on reducing the upward movement as they did on increasing it.

Further investigation after the removal of non-historic cement stucco on the exterior surface of the dome indicated the source of the anionic nitrate salts. A substantial part of the building mass originally constructed to receive the thrust from the dome consisted of earth fill. This fill contained a significant amount of decaying, or decayed organic matter relatively high in concentration of nitrates. The cracked exterior cement stucco allowed moisture to penetrate down to this earth fill material and then, eventually to surface on the interior of the dome.

Another indication that moisture was moving through the dome from exterior to interior at that corner was a light yellow-green discoloration which appeared in concentric rings on the pendentive. The efflorescence always formed on the outer edges of this stain. It was at first thought that the stain could be organic but later was determined by proton induced x-ray emission to contain trace amounts of copper and nickel. Apparently, the minerals appeared in a spot on the pendentive and created the stain as moisture moved from within the masonry mass of the pendentive to the interior surface.

Recently, horizontal holes were drilled to a lateral depth of two feet in the area of the northwest pendentive from the exterior of the structure. Material samples were taken and a determination of moisture content made. At the two feet depth, lime plaster or mortar was encountered which was probably the interior portion of the pendentive where it was set into the mud brick wall. The moisture content was approximately ten percent at that depth. This leaves little doubt that water was percolating down from above and was migrating to both the exterior surface of the adobe wall and the interior surfaces of the pendentive, dome and wall.

Ambient Conditions

Conditions inside the Sanctuary were monitored to determine if there were causes of deterioration in addition to rain water moving through the dome. The elements of the monitoring were: (1) recording of relative humidity and temperature at both the floor and dome levels, (2) recording the surface temperatures of the dome on the north, south, east and west, (3) recording relative surface moisture, (4) recording the amount of air movement at critical points, and (5) recording the amount of total solar radiation on vertical planes at the northwest, northeast, and southwest corners of the interior of the Sanctuary.

The purpose of recording the relative humidity was to determine, in combination with the recording of the surface temperatures, whether or not conditions exist which would lead to condensation of ambient moisture on the dome or wall surface. At no time was the relative humidity in the dome ever over 60 percent during the recording period and the normal was closer to 40 percent. A maximum differential between the ambient temperature in the Sanctuary and the surfaces was five to six degrees Fahrenheit. This difference occurred on the north portion of the dome surface. For condensation to form a combination of a six degree Fahrenheit temperature differential at approximately 90 percent relative humidity is required. At 60 percent relative humidity the temperature on the surface would have to be approximately 15 degrees cooler than the air. Obviously, the conditions did not exist for condensation to take place on surfaces unaffected by the hygroscopic salts of efflorescence.

A relationship between the relative humidity near the floor of the Sanctuary and up within the dome has been established. At high relative humidities near the floor in the 60-80 percent range, the relative humidity at the dome will be between 30-45 percent. When the Sanctuary floor range is 30-45 percent relative humidity, the dome relative humidity will be in the 15-30 percent range. The surprisingly large difference cannot be attributed to temperature difference since they will only vary a few degrees. In fact, at times the temperature immediately below the dome will be a few degrees lower. This apparent heat loss can probably be attributed to convection. A curved surface has a larger convection heat-transfer area and since much more heat is lost by convection than by radiation, a curved roof is more easily cooled.

The temperature difference from the sun side to the shade side on the interior surface of the dome is related directly to the exaggerated difference on the exterior surface of the dome. This temperature difference of more than 60 degrees Fahrenheit or 33 degrees Centigrade has been recorded and a difference of 50 degrees Fahrenheit is quite common on the exterior. This difference is the reason for many of the cracks in the cement stucco that covered the dome. A temperature difference of as much as 50 degrees Fahrenheit between the cement stucco and the original dome also contributed to the loss of bond between the two. However, the temperature difference on the interior surface of the dome from one quadrant to another is never more than three degrees Centigrade.

The relative amounts of surface moisture were measured several times on the interior of the dome with a surface resistivity meter. However, this aspect of the monitoring in this particular case contributed little. Those areas which exhibit the greatest amount of deterioration gave higher readings, indicating a relatively greater amount of surface moisture. These areas also have the greatest amount of recrystallized salts on the surface which would give a higher reading with the same amount of moisture as areas which had less surface salts. The surface surveys did seem to indicate that some areas which had deteriorated greatly in the past had become somewhat stabilized with less of an indication of surface moisture.

The movement of air in and just below the volume defined by the dome appears to be minimal. On several different occasions the amount of air moving near the northwest corner was measured and compared to the movement of air through the sacristy door and along the nave wall. At no time was the movement up in the dome greater than one kilometer-per-hour and an average over a period of several hours would be significantly less than that. Over the same period of time the air movement through the sacristy door would average five kilometers-per-hour, being greater than seven kilometers-per-hour on occasion. The movement in the nave would average approximately one to two kilometers.

As previously mentioned it is difficult to explain the relationship of the relative humidities to the dome and near the Sanctuary floor. Obviously, the air in the lower portion of the Sanctuary is not being mixed well with the air in the upper portion. One reason would be that the air moves from the open sacristy in through the Sanctuary, down the nave, and out the front door with little obstruction. Of course, the reverse air movement also occurs. In either case the air in the dome apparently moves very little, not being influenced either by the lower air movement.

From the standpoint of conservation, the more stable conditions in the upper portions of the dome are preferable. It is undesirable to increase the air movement in this area and in fact it is more desirable to decrease the movement of air through the lower portion as well. Air moving through the Sanctuary has deposited a large amount of soil particles over the past 30 years and will continue to do so. Closing off the access of exterior air would certainly minimize the amount of particles deposited in the dome area but minimal air movement may be desirable.

Plaster

A significant amount of plaster sounds hollow when tapped. This hollow sound has been interpreted in the past as a sign of the lack of bonding between the plaster and the mud brick or fired brick. This interpretation is not entirely correct since a variation in plaster thickness will also produce a variation in the response. There is no doubt that some of the hollow response reflects a lack of bonding, but even in many of these areas the plaster is soundly attached to the wall by effective plaster keys at the mortar joints. These keys are the results of the mud mortar joints being cleaned out, often to a depth of 5-7 centimeters and the base coat forced into these voids during the original application of plaster.

The lime plaster in the past has fallen from the face of the wall when, either rain water erodes away these plaster keys, or the keys have been sheared as differential movement occurs between the plaster face and the mud brick walls. A combination of these two factors are normally involved as the load carried by a plaster key is increased beyond its carrying capacity when adjoining keys are eroded away. This particular situation has not resulted in the loss of any plaster over the past 60 years, or since the church was reroofed and the interior surface was no longer subject to extensive rain water. However, a significant amount of plaster appears to be unstable and this is today the primary conservation concern.

The problem has been dealt with in the past at Tumacacori in two ways. The most prevalent method was to apply a cement bead around all the exposed edges attaching this bead to the walls by some mechanical device such as pins. Much larger steel pins were also used in one section of plaster to replace the effects of original plaster keys that were feared to be of questionable integrity (Sudderth, 1973). Holes were drilled through the plaster and into the mud brick walls. The exterior edge of the hole and the plaster itself were grouted in an attempt to attach the head of the steel pin to the plaster (Figure 6).

The results of this work have been ineffective. In addition, several adverse side effects have arisen and contributed to the deterioration of the plaster. Initially, there was a separation between the steel and the grouted plaster, probably because of the difference in the coefficients of thermal expansion of the two materials. The second and the most deleterious effect was the deterioration of the plaster in an area approximately 10 centimeters in diameter around the head of the pin. This was caused by the condensation of internal wall moisture on the steel and its concentrated movement from the inside of the wall to the plastered wall surface.

A recent extensive survey of the conditions identified four relatively large sections of plaster that appear unstable. The largest of these is approximately three square meters in size. Many other smaller areas up to one square meter in size, most of which are located in the Sanctuary, also appear unstable. This evaluation is based on visual observations, soundings, and the injection of extremely low air pressure behind the plaster in areas of suspect integrity. Earlier, a microwave survey had been conducted in an attempt to determine whether or not voids existed behind plaster. While valuable information was produced related to internal wall moisture, small voids or the delemination of lime plaster from the wall could not be determined using this particular system. Interestingly enough this microwave system was sensitive enough to distinguish between the mud bricks and the mud mortar used to bind them together (Belsher, 1979).

Another condition existed primarily on the plaster in the Sanctuary that was causing significant damage. Because of inadequate preparation originally, large nodules of calcium carbonate, from two to five millimeters in diameter existed in the layer of finish plaster. These nodules would expand as free moisture came in contact with them as it moved from the interior of the wall to the wall surface. The expansion of the nodules resulted in small pock marks on the surface of the plaster as they disintegrated or were extruded. At the time when the moisture movement was at its greatest, new pock marks could be detected daily.

TREATMENT OF PROBLEMS

Various treatments have been undertaken or completed that deal with specific problems while other possible treatments are still being evaluated. The actual treatments are also being evaluated and will continue to be monitored as to their appropriateness.

Removal of Inappropriate Cement Stucco

As has been mentioned previously, most of the exterior surface of the mud brick walls and the Sanctuary had been covered with a portland type cement stucco during the 1940's and 1950's. The principal effect of this relatively impervious surface coating was to increase the capillary rise in the walls by decreasing the natural evaporation of moisture on the vertical surfaces.

The effect on the painted plaster in the Sanctuary was quite drastic as rain water penetrated through the cement stucco and then eventually moved through the mass of the dome, since evaporation up through the cement stucco was restricted.

The cement stucco was removed from the mud brick walls during the summer of 1978 and was replaced with a lime-sand plaster that closely resembles the original plaster in color and texture as well as its important characteristics related to moisture movement. Since this time, the walls have continued to dry even though the capillary movement in the walls from the ground has not been completely eliminated.

The cement stucco on the dome was removed and replaced with the same lime-sand plaster used on the wall surfaces. The earth fill which proved to be the source of the nitrate anions was removed and replaced with low fired bricks set in lime mortar (Figure 7).

Immediately after the dome area was replastered there was a drastic reduction in the amount of efflorescence that formed on the interior surface. This immediate change reflects more the removal of the damp earth fill than it does the effectiveness of the new lime plaster. However, the effectiveness of this more appropriate covering will be more evident in the future.

Cleaning the Interior Plaster Surfaces

In January of this year the large accumulations of dust and dirt were removed from all vertical and horizontal surfaces during the extensive survey of the interior plaster. The salt incrustations on the interior surface of the dome were not removed, but will be in the immediate future. The cleaning was accomplished with soft bristle brushes of various sizes often in association with a vacuum so that the loosened particles would not recirculate, simply to settle again later. It was discovered at the time of the investigation that the earlier cleaning technique used in 1949 during the work by Gettens and Steen was essentially to abrade away the soiled areas with stiff bristle brushes that more often than not also removed some of the historic wash. Small knives and picks were used this year in some areas, also, but some of these will require more attention. The areas needing more attention were identified and recorded for more extensive work later.

Several solvents such as acetone and toluene were used on areas of the wall to reduce the sheen which remained from the PVA applied in 1949. Cellosolve, a trade name for ethylene glycol monoethyl ether, was also used as it was one of the solvents used originally. Solvents were also used in stained areas which were suspected to have caused by, or influenced by the PVA.

An attempt was also made to use water to remove some of the accumulated particles and stains. It did not prove to be viable however as the water was difficult to control and more often had the tendency to carry small particles into the surface plaster wash, especially if associated with any abrasive action. The outer portions of some large streams of mud, some up to 5 millimeters thick on the vertical wall surface that were caused by rain water from a leaking roof, could be removed more easily with water. However, extreme controls were necessary to localize the water to keep it away from the plaster itself and since there was little real advantage over the use of the soft brushes, the use of the water was not pursued.

Reattachment of the Paint Film

Experiments are currently being conducted to determine the most appropriate methods and materials to reattach the paint film in the Sanctuary to its plaster ground. Some materials such as soluble nylon do not appear to be strong enough to be effective in most situations. A 10% solution of Acryloid B72 in toluene was also used on several test areas. Earlier, a 25% solution of Acryloid 134 was used and showed some promise. These as well as ethyl silicate solutions will continue to be evaluated until the next phase of the conservation work is undertaken this winter.

In any case, a treatment of overall coverage, similar to the earlier work will not be done this time. Localized treatment of friable and loose edges, or limited area coverage is more appropriate so that natural moisture movement in and through the material will be influenced only minimally.

Filling of Pock Marks

Pock marks resulting primarily from the hydration of nodules of calcium carbonate are being filled to eliminate a cavity where air borne particles could more easily accumulate. This is not done as part of a restoration program since restoration or painting reconstruction is not being undertaken here, but rather from the perspective of conservation.

Experiments have been conducted using several material combinations with lime grout as the basic ingredient and are being evaluated. However, the most promising material has been a cellulose filler manufactured under the trade name of Polyfiller. This material holds together well while being used and because of the rather difficult working conditions often encountered, proved to be an advantage over some lime grouts and putties. Pigments can also be added and in some situations at Tumacacori, this is desirable. There is also no shrinkage and that is extremely important in many use situations.

Reattachment of Lime Plaster

The primary problem that remains unresolved at Tumacacori is finding solution to the lack of bonding of specific areas of lime plaster to

mud brick walls. The steel pins used previously were not successful, although the use of pins to simulate the effect of the original plaster keys seems to be logical.

Several techniques and materials have been used in an attempt to reattach the entire back surface of plaster to the adobe surface but only one has showed any promise. The common application method for these is the injection of the adhesive, or adhesive-consolidant into a void between the plaster and the wall.

The surface of mud bricks onto which the plaster is attached is normally extremely friable and most adhesive materials simply would not bond to the adobe. In contrast most materials adhered to the back side of the plaster adequately.

The only injected material that was successful was a flexible epoxy resin. This specific epoxy resin was first used for this purpose at Fort Bowie National Historic Site in 1973 (Kriegh, Sultan, 1974). The conditions of the mud brick walls at Tumacacori and Fort Bowie are quite similar. The environmental conditions are also quite similar as they are both located in the same general geographic area. The integrity of the reattached lime plaster and the epoxy resin appeared sound after six years. This same formulation was used on an experimental basis at Tumacacori in 1979 and was highly successful in penetrating into and consolidating the friable surface of the mud bricks as well as the lime plaster. Penetration into the walls was in the range of 8-10 millimeters and up to 20 millimeters into the lime plaster. In one case the epoxy resin actually penetrated completely through a thinner section of plaster. This is a potential problem that will have to be addressed during future applications. The primary disadvantage encountered pertained to the actual injection process and the actual conditions of the plaster and associated mud brick wall. Often the void between the plaster and bricks was extremely large and filled with friable material from both the brick and plaster. Some of this could be removed with a suction or vacuum tube but it was never possible to remove all this material. Consequently that that remained normally prevented the plaster from being pressed back against the wall to reduce the size of the void. Consequently, greater amounts of the epoxy resin had to be used and care had to be taken not to increase the pressure against the inside surface of the plaster causing it to be pushed off even more.

The epoxy resin formulation consists of:

Epirez 5081	100 parts by weight (pbw)
Colma Dur LV Curing Agent	35 (pbw)

Epirez 5081 is manufactured by Celanese Coatings Company, Louisville, Kentucky. The Colma Dur LV curing agent is manufactured by Sika Chemical Corporation of Lynhurst, New Jersey.

Another possibility being evaluated currently is a combination of materials, one used to consolidate the friable mud brick surface and another used to adhere to both the consolidated wall and the lime plaster. One problem with this particular technique is its use in areas that are behind large expances of plaster and cannot be seen directly or the materials manipulated easily.

Epoxy resin pins of the formulation given above have also been used on an experimental basis. This seems to give the best promise for a permanent solution. The principal is to simply replace the effect of original plaster keys where they are missing, and to rely on the tensile strength of the plaster in the areas where the pins are not placed (Figure 8). The ability of the epoxy resin to consolidate both materials will make it possible for the resin itself to hold the plaster surface to the pin. If one does not exist, it will be necessary to drill a hole through the plaster and into the brick, but this hole can be filled with a lime grout or another appropriate material such as the cellulose filler.

The depth of the pins into the wall will vary depending on the integrity of the bricks near the surface. In some unusual cases it seemed necessary to extend the pins as much as 30-45 centimeters into the wall. However, in most situations a depth of 10-15 centimeters seems more appropriate. Of course the length of the pins and its depth in the wall will also depend somewhat on the amount of plaster that is being supported.

CONCLUSION

Because of the rather limited extent of this particular site and because of the size of the extant buildings many preservation problems at Tumacacori can and are being dealt with from a standpoint of cyclic maintenance. If it is technically or financially impractical to totally eliminate a cause of deterioration, such as the total elimination of capillary moisture in the church walls, the affected area is repaired periodically. In fact, a totally static situation when no further change to the material would ever take place is not necessarily desirable even if it were possible. Consequently, repair to the mud bricks is done using traditional methods and materials if they do not accelerate deterioration in other areas.

The painted lime plaster on the interior of the church is somewhat different in that it cannot simply be repaired when further deterioration takes place. In this case the elimination of the causes of deterioration is the goal. Repair, such as the reattachment of lime plaster to mud brick walls, is different than simply replacing eroded mud with more mud. It is more permanent and more importantly, it involves adding a new material to replace a function, rather than a new material to replace an older material.

Where there are problems involved with the use of a flexible epoxy resin to replace the function of the keying of the plaster to the walls, it appears at this point to have the most promise. Still the problem of the reattachment of the lime plaster is seen as the most significant problem to be totally solved at this particular site.

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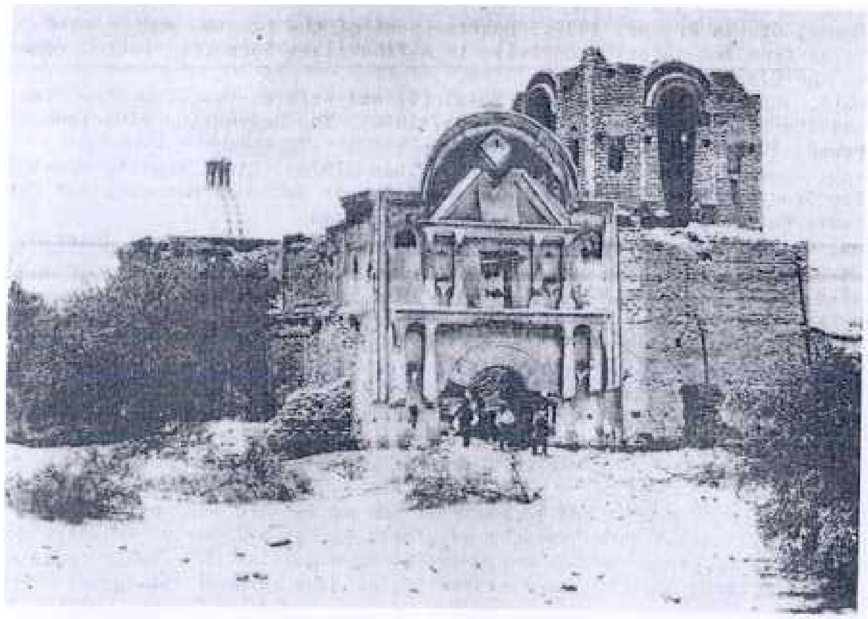
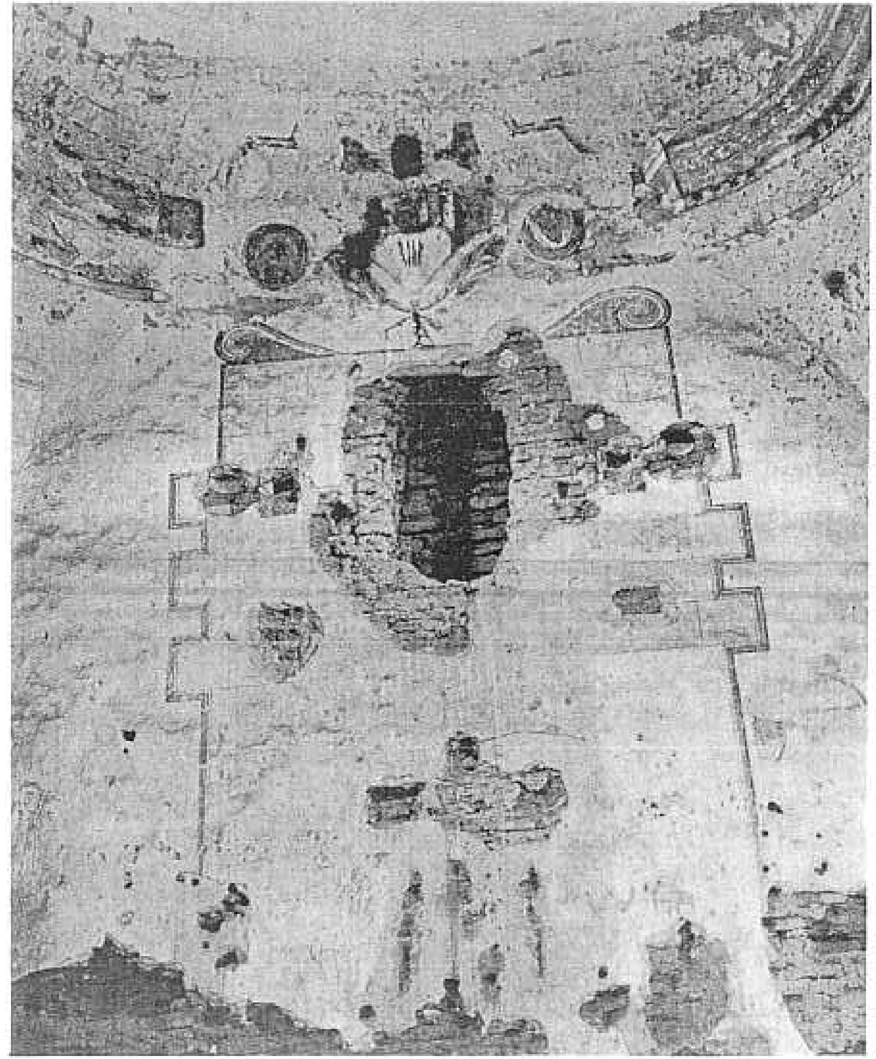


igure 1: Church at Tumacacori in 1889. Photograph #2546, Arizona Historical Society, Tucson, Arizona.



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HABS photograph 37

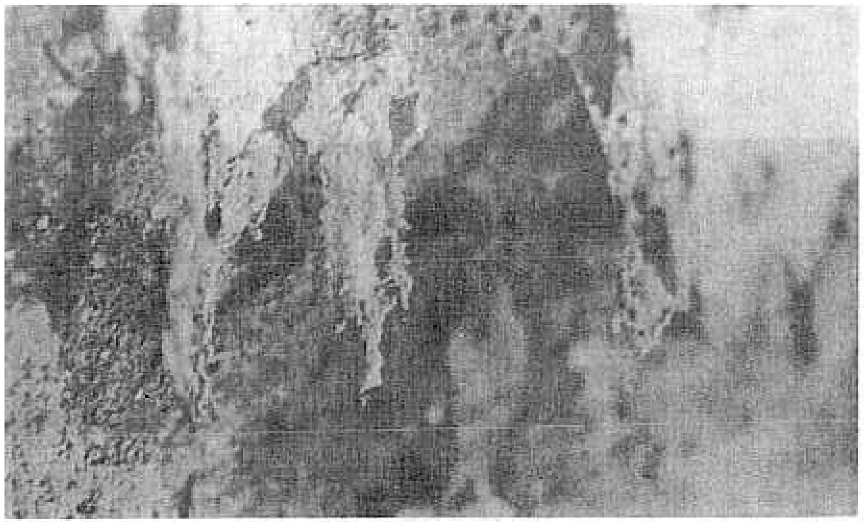

Figure 3: Deteriorated dome plaster with PVA applied in 1949 hanging from the surface in thin net. NPS photograph, 1979.

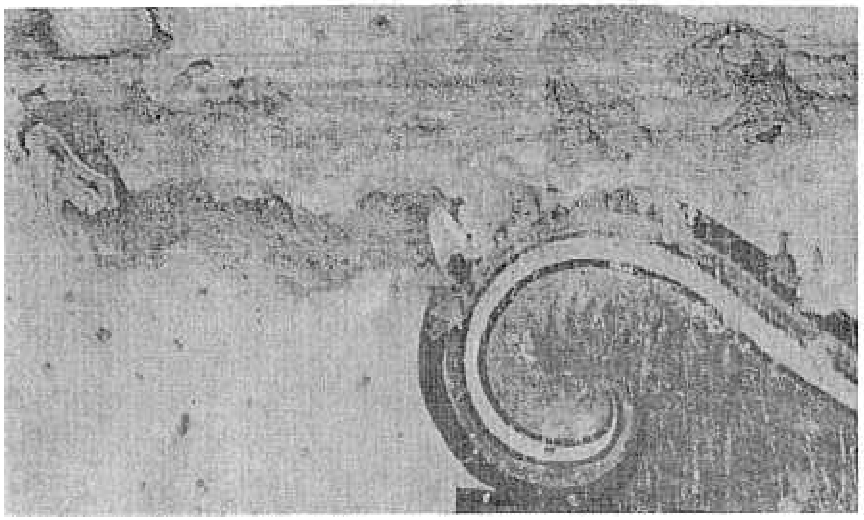

Figure 4: Painted plaster in Sanctuary. Note the paper along the top edge of the painted volute that was used in an attempt to temporarily reattach the paint film to the plaster ground. NPS photograph, 1976.

Figure 5: Plaster surface with extensive deterioration by efflorescence forming on the surface and immediately beneath the paint film. NPS photograph, 1979.

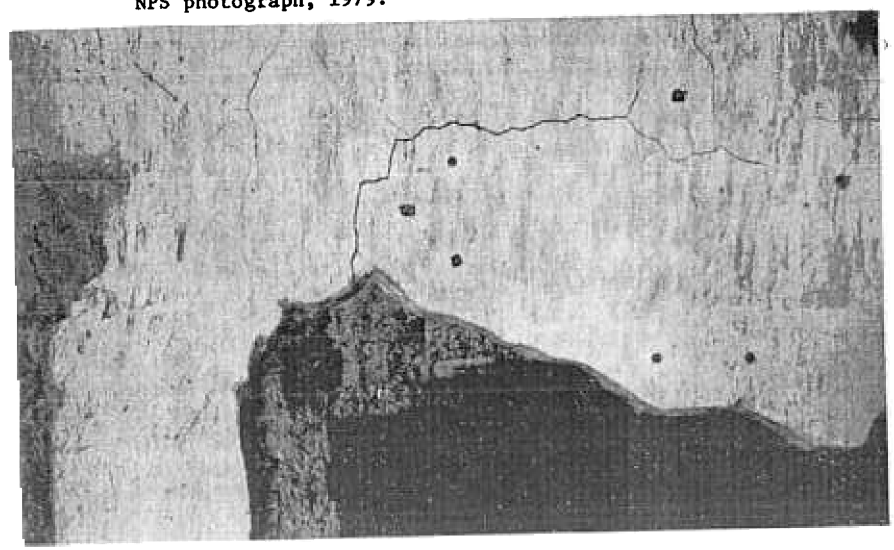

Figure 6: Plaster on interior surface west of the nave wall. Small dark spots are the locations of the steel pins used to secure the plaster to the mud brick walls.

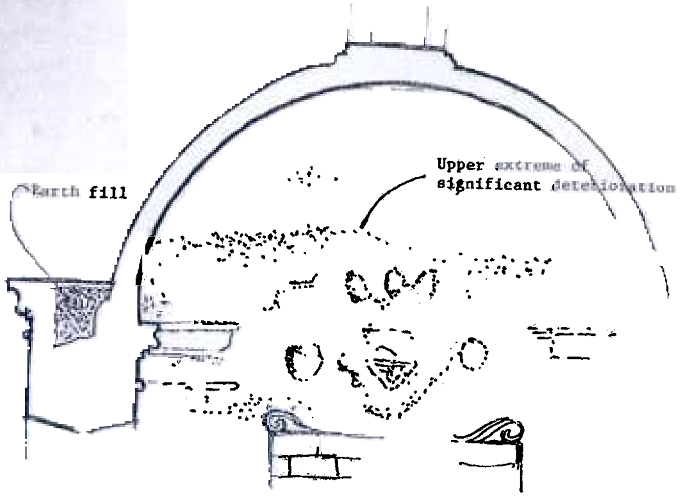

Figure 7: Partial section through the dome showing the location of the earth fill.

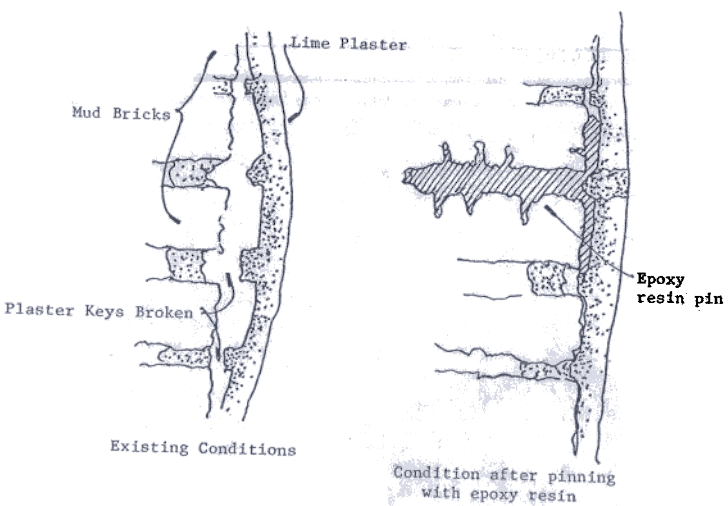

Figure 8: A typical use of an epoxy resin pin to reattach lime plaster to the mud brick wall.