TREATMENT REPORT

Analysis and Conservation of the Great Hall Ceiling

DRAYTON HALL
CHARLESTON, SOUTH CAROLINA

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INTRODUCTION

Drayton Hall, located outside of Charleston, South Carolina, is well known as one of the earliest and certainly one of the finest examples of Georgian Palladian architecture in the United States (Fig.1). From the time of its completion in 1742 until the American Civil War, it served as the principle residence and symbolic seat of the descendants of John Drayton, a family of major influence and achievement in the history of the colony and state of South Carolina.

Following the Civil War, Drayton Hall endured twenty years of decline and depredation. That the building survived the war at all, avoiding the fate of nearly all the neighboring plantations on the Ashley River, adds to its significance. The survival of Drayton Hall to the present can be attributed to a mixture of good fortune, to the building's inherent solidity, and in no small measure to the devotion of the Drayton family.

After the National Trust for Historic Preservation acquired the property from the family in 1974, a period of intense evaluation of the condition of the house began. Areas of deterioration were repaired or stabilized as needed over a period of several years. Preservation rather than restoration was prescribed in recognition of the high architectural integrity of the house.

Soon a desire to open Drayton Hall to visitation necessitated an evaluation of the live load capacities of the various structural systems throughout the house. In 1977, a structural analysis of the building identified several deficiencies including the ceiling framing of the Great Hall.[1] The distance spanned by the joists was found to be excessive for their dimensions resulting in a live load capacity of only 14.2 pounds per square foot for the floor, inadequate by modern standards to safely support the load of large groups of visitors. In

[1] Robert A. Shoolbred, Inc., Report on the Structural Analysis of Drayton Hall for the National Trust for Historic Preservation, Charleston S.C., 1977. Unpublished Report.

addition, it was believed that the large span-to-depth ratios of the undersized joists caused excessive deflections of the floor in the second floor Great Hall and subsequent cracking of the plaster ceiling below.

During the same year, a study of the ceilings also identified several problem areas including the Great Hall, where cracking and plaster to lath detachment were especially severe (Fig. 2).[2] As a result, the second floor was closed to visitor traffic until the ceiling of the Great Hall could be structurally improved and a series of measures were outlined for the total reattachment of the ceiling. Beginning in the spring of 1978, the following sequence of procedures for the stabilization of the Great Hall ceiling was performed (Fig.3)[3]:

- Installation of temporary shoring (a)
- Removal of floorboards (b)
- Removal of damaged plaster and damaged keying (b)
- Cleaning of debris from joists and lath (b,c)
- Application of acrylic bonding agent to joists, lath, and plaster (c)
- Insertion of U-shaped channels of galvanized steel wire mesh into joist spaces (d)
- Attachment of suspension wires to mesh (d)
- A continuous pour of plaster of Paris in each joist bay intended to set to a depth of ¾ - 1" (e,f)
- Installation of steel angles to the sides of the joists (the bolts used to attach them also fastening the mesh to the sides of the joists) (g,h)
- Installation of aluminum angles across each joist space to rest on the lower steel angles (i)
- Attachment of the suspension wires to the aluminum angles (g)
- Replacement of the existing flooring

[2] John G. Waite, An Evaluation of the Condition and Preservation Potential of Decorative Plaster Ceilings at Drayton Hall, Charleston, South Carolina, Albany, NY, 1977, Unpublished Report.

[3] Photodocumentation of the 1978 stabilization was recently discovered at Lyndhurst in Tarrytown NY. Digital copies of the treatment photographs are now on file at Crayton Hall.

During the work, the original bridging boards between the joists were removed, probably to accommodate the steel bracing. At the time, no cosmetic treatment was performed on the exposed plaster surface below.

The second floor Great Hall was re-opened to visitor traffic once the structural reinforcement and plaster reattachment were completed. However, in the decade that followed, new concerns arose over the stability of the ceiling. As a result, the National Trust for Historic Preservation convened a colloquium of professionals in 1990 to investigate the situation. The assembled experts were unanimous in their recommendation that a survey of all existing conditions was an absolute prerequisite for any program of monitoring or consideration of possible additional treatments.

Participants at the colloquium were also in agreement that visitor traffic, with its suspected attendant vibration and deflection of the supporting structure, needed to be isolated from the system if the monitoring of other potential mechanisms of deterioration (e.g. moisture and temperature variation) were to be of any value. Because of this and a desire to protect the ceiling from any further visitor-related damage, a technologically advanced fiberglass walkway-bridge was installed over the floor framing of the second floor Great Hall. Although originally scheduled to remain in place for a period of two years, while the ceiling was studied and future courses of action were determined, the bridge remained for twelve years until 2002 when the present intervention was finally realized.

In response to these recommendations, an in-depth study of the Great Hall ceiling was conducted in 1991 by the Architectural Conservation Laboratory of the University of Pennsylvania (ACL) at the request of The National Trust for Historic Preservation. The study synthesized physical evidence and documentary sources with a detailed conditions survey of the plasterwork to reveal a complex and informative history of the house and ceiling over a 250-year period.

The survey, with its superimposed layers of conditions and framing construction, identified probable causes of plaster failure and conclusively showed a correlation between the location and direction of the plaster cracking and the placement of the joisting. As no detailed condition survey had been executed prior to the 1978 stabilization work, a visible assessment of its efficacy in 1991 was almost impossible.

Since 1991, several coordinated technical studies have been pursued at Drayton Hall to develop sensitive solutions for stabilizing the interior fabric of the house including structural, material and environmental intervention.[4] As part of this effort, the ACL returned at the invitation of the National Trust to implement conservation treatments to the Great Hall ceiling. The 2001 plaster ceiling conservation project addressed both condition reassessment and treatment and included four tasks:

- **Temporary Stabilization-**To protect and support sensitive areas of the ceiling during the installation of the structural retrofit and reinstallation of the wooden floor above.
- **Condition Reassessment-**To resurvey the ceiling using the data from 1991 and identify any changes since the earlier survey. Additionally, all data including the 1991 survey was incorporated into digital drawings using AutoCAD® and CAD overlay®. An experimental program of analysis utilizing GIS was also independently developed as part of this task to verify the validity of the collective assumptions about the ceiling conditions, causes of failure, and the validity of intervention strategies.
- **Treatment Design and Evaluation-**To design and conduct a treatment testing program to determine the most appropriate method for reattaching delaminated sections of the ceiling. Using standards developed by RILEM and ASTM, tests were conducted to provide comparative data on the treatments selected for testing.
- **Priority Treatment Implementation-**To implement plaster conservation treatments to areas where failure was identified as existing or immanent. This was greatly influenced by the GIS analysis which afforded better modeling of the collective conditions posing real and potential threats to the stability of the ceiling. As a result of this analysis, the original location of the structural retrofit and visitor access above was reconfigured.

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[4] Ford Farewell Mills and Gatsch Architects, Architectural Engineering and Conservation Study of Drayton Hall: Technical Report, Princeton New Jersey, VII-1, 1998. Unpublished Report.

THE GREAT HALL

DESCRIPTION

The Great Hall is one of the largest (29’ x 23’) and most important rooms at Drayton Hall. Centrally located on the first floor, the room has served as the main entrance to the house on the approach from the landside since its construction. Its current ceiling, installed during the 1860’s, is comprised of a flat field of lime-gypsum plaster decorated with applied cast gypsum relief. This ornamentation includes a large central composite medallion of stylized local vegetation and a border of stars and small roundels located at the corners and midpoints of the room (Fig. 4).

The framing system of the second floor above the Great Hall is composed of seventeen joists laid on a north-south axis and notched onto a timber plate set into the load bearing brick partition walls (Fig. 5). These joists have been identified as Southern Yellow Pine, reciprocally sawn, spaced approximately 17 inches on center and measuring approximately three inches in width, ten inches in height, and approximately 30 feet in length. Adjacent to both sides of the fireplace, two 3” X 10” joists are fastened together with iron bolts forming two 6” x 10” composite beams in order to provide additional support for the fireplace hearth. The span of the joists in comparison to their height is too great, yielding a live load capacity of only 14.2 pounds per square foot.[5] The large span to depth ratio of these members allows the joists to deflect as well as to move independently under live load conditions to a degree in excess of that tolerated by the plaster ceiling suspended below. This has resulted in a series of large cracks in the plaster that run the length of the room parallel to the joists. Less prominent cracks perpendicular to the joists have

[5] Robert A. Shoolbred, Inc., Report on the Structural Analysis of Drayton Hall for the National Trust for Historic Preservation, 1977, Charleston S.C., p.4.

also formed which allow the long strips of plaster between the joists to flex under live loads as a series of articulated plates of various size (Fig. 6).

Attached to the joists with machine-cut nails, are twenty 3” x 3” x 10’ diagonal braces (ten on each side of the room) of circular sawn Southern Yellow Pine, which span between the top of one joist and the bottom of the adjacent joist. The shorter diagonal braces (3” x 3” x 6’) in front of the fireplace bear notches in order to accommodate bridging boards which were removed in the 1978 campaign.

The Great Hall ceiling plaster is keyed to circular sawn lath attached directly to the joists with small machine-cut nails. The fact that only one set of nail holes has been found on the joists indicates that the present lath and plaster ceiling is probably the only one to have been applied to these joists.

CONSTRUCTION HISTORY

The present ceiling in the Great Hall is believed to be its third, probably installed in the 1860’s in response to the need to relieve load from the heavy summer beams that were originally located at the third points in the room. The original eighteenth century faming of the ceiling appears to have been a three bay system with the joists spanning approximately ten feet to summer beams, whose dimensions were approximately 11” square (Fig. 5). While the design of the original ceiling cannot be determined from any surviving physical evidence, it is clear that the Georgian ceiling was at least one to three inches lower than the current ceiling.

At some unknown date, but probably during the early nineteenth century, the original ceiling of the Great Hall was replaced with a ceiling ornamented in a manner typical of the Federal period, with delicate and attenuated neoclassical motifs. This ceiling survived at least until circa 1845, when a drawing was made of it (Fig. 7).[6]

This framing and ceiling system appears to have been converted some time between 1855-1874 to the present system. There is good evidence to suggest that the revised framing was much too flexible from the beginning, probably before the plaster ceiling was ever installed. It is likely that the twenty diagonal braces were installed from underneath the floor during construction. The braces were probably intended to add rigidity to the joists but, unfortunately, their ability to stiffen the floor was negligible.[7] The braces appear to have been an afterthought and not part of the original design; their insertion required the removal of several of the bridging boards, which clearly were part of that original conception. It seems likely that the floor was a disappointment in terms of its excessive flexibility. This made immediate alterations necessary in an attempt to stiffen the floor before the plaster had even been applied to the ceiling below.

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[6] Gibbes's sketchbook is the only known document of the appearance of the Federal ceiling. Among several drawings of Drayton Hall, its furnishings, and outbuildings, is a ca. 1845 drawing of a ceiling ornamented in the manner of the Federal period. Such a ceiling could have fit the dimensions of the second floor Great Hall (201) as easily as those of the Great Hall, but Gibbes provided another illustration of the same ceiling superimposed on a plan of Drayton Hall that also depicts the ceiling still extant in the "Ionic" Drawing Room (102), suggesting that Gibbes was illustrating features on the first floor of Drayton Hall.

[7] Although the braces act most effectively to counter deflections of the joists along the horizontal plane due to warping, their length and vertical angulation suggests that the braces were mainly intended to stiffen the joists against vertical deflections. The attempt to stiffen the floor frame with these braces appears to have been empirically based and doomed to failure. In order to remain concealed within the floor space the braces had to be set at too shallow an angle to be of any significant mechanical advantage against load-induced, vertical deflections of the joists.

CONDITION ASSESSMENT

The 1991 and 2001-02 studies of the plaster ceiling and its framing were executed using non-destructive techniques. The architectural fabric was thoroughly examined in order to determine whether specific elements might exhibit evidence indicative of alteration. This was also done to correlate the structural behavior and failure of the various materials and assemblies in association with each other (e.g., framing, plaster, and previous stabilization systems). A conditions assessment of the plaster ceiling was conducted primarily through visual examination. The following conditions were identified and graphically recorded on a rectified photomontage: cracking, detachment, patching, adhesive repair, pitting, staining, missing ornaments, and plaster loss. In 1991 areas of blind detachment were also identified through percussive sounding. Annotated drawings of existing conditions of the framing system, joist by joist, and the plaster ceiling were prepared as well (see Fig. 6).

In additional to structural analysis and a survey of conditions, analyses of the wood, plaster, and mortars were undertaken in 1991 and 2001 to assist in dating and diagnosing the conditions of the framing and plaster ceiling. Wood species were identified, and mortars and plasters were chemically analyzed.

A review of past explanations for the failure of the Great Hall ceiling reveals a consistent belief that deflection of undersized joists was the primary cause for cracking, with vibration contributing to secondary detachment. More recent hypotheses have added the possibility of continued keying failure, lath detachment from nail corrosion, and thermal movement to explain what has been considered random crack patterns.[8] Opinions have also varied on the success of the 1978 structural retrofit and plaster stabilization. Theoretical calculations suggest that, while ultimate strength was improved, vibrational stiffness was not.

[8] Ford Farewell Mills and Gatsch Architects, Architectural Engineering and Conservation Study of Drayton Hall: Technical Report, Princeton New Jersey, VII-1, 1998. Unpublished Report.

Moreover, the steel reinforcement has added approximately 4500 pounds of additional dead load to the existing ceiling system. This has certainly increased the deflections of the joists through creep since their installation and has probably enlarged the existing cracks. This alone may be the source of the observed “worsening” of the ceiling reported after the repairs.

While the study of the structural system and its responses to stress have been possible through direct observation, the plaster condition is more difficult, given its concealment by the 1978 stabilization work. There is no doubt that these treatments improved the perilous condition of the already detached plaster. It is also clear that reattachment was only partially successful given the inability of the method to reach all detached areas from the top. This has been confirmed during recent examination in numerous locations where blocked voids and hairline detachment did not benefit from the liquid Plaster of Paris pour. (Fig. 8)

SUMMARY OBSERVATIONS

Based on the 1991 investigation and subsequent studies in 1998, the following observations and assumptions were made regarding the condition of the Great Hall ceiling prior to the 2001 conservation reassessment and treatment:

- A network of roughly orthogonal cracking can be observed across the entire ceiling. The majority of the large cracks, readily distinguished from other cracks in the ceiling, run parallel to the long axis of the room and is closely associated with the joists located above them. Their slightly meandering quality suggests that they are not consistently below the centers of the joists but also may occur to either side of a joist at a given location. This pattern can be explained by the differential movement and shear cracking between joists, as well as tensile cracking across joists.
- The condition of detachment as determined by percussion is invariably associated with cracking, with a greater correlation between detachment and large cracks than any other crack type.
- Loose ornaments tend to be associated with cracks in the flat plaster, which appear to pass under or around them.
- Pitting, loose and missing ornaments, and patching all tend to occur in a zone approximately 5 feet wide, which crosses the short dimension of the room at its midpoint. This zone is suspected to

have been subject to previous moisture infiltration. The repaired area of the ceiling near the Stair Hall suggests the site of the most severe damage.

- These overall conditions predate the opening of the house to the public as evidenced in the 1938 Frances Benjamin Johnston photographs of the Great Hall (Fig. 4). Worsening of the plaster cracking and detachment would have occurred as a result of increased live load from visitation.
- No quantifiable evidence of condition changes can be made between the 1978 stabilization and 1991, when the bridge was installed.
- The stabilization treatments of 1978 did reattach those areas with broken and removed keys and where there was sufficient plaster detachment and voids for the gypsum pour to flow between the underside of the lath and the scratch coat. Any detachment of the ceiling caused by the release of the lath from the undersides of the joists (unconfirmed) would have been corrected by the continuous contact of the gypsum-mesh application to the top of the lath (Fig. 9).
- Analysis of the base coat of plaster reveals a high clay to lime ratio that probably accounts for its high friability, low tensile strength, and poor bond strength with its thin gypsum finish coat.
- The treatment did not reattach areas inaccessible to the pour and those areas of keys with hairline cracks, scratch coat separation and narrow gaps (Fig. 9).

DOCUMENTATION

The existing plaster ceiling of Drayton Hall's Great Hall, installed in the 1860's probably began to crack and detach from its lath support soon after installation, and certainly by the time of the first known available photograph taken of the ceiling in 1938 (see Fig. 4). In preparation for treatment, the 1991 documentation of conditions was extended to include size of cracking based on width, direction of vertical displacement of cracking, as well as others. Additional collected data included exact locations of major ceiling features to assist in the creation of a CAD drawing, to be used as a base map for all survey data as well as treatment documentation. Using triangulation from two datum points, measurements of over 600 ceiling points were taken which included major decorative elements as well as the intersection of all major crack intersections.

A preliminary comparison of existing 2003 conditions with the 1991 survey indicated that interventions in the past taken to prevent continued deterioration of the ceiling had been successful. Clearly the installation of the bridge over the floor of the second floor Great Hall had significantly reduced continued deterioration by removing visitor live load. Ironically the greatest damage to the ceiling occurred during preparation for Hurricane Hugo in September of 1989 resulting from a slip and fall accident (Fig. 10). All detached material from this area was carefully saved and was later used for laboratory analysis and treatment testing. Surviving decorative plaster was individually bagged on site and sent back to the ACL for repair work. Two different types of delamination were observed which included detachment from the lath substructure as well as inter-layer delamination. These two types of conditions were not differentiated in the 1991 survey but were seen as uniquely different in the same assessment done in 2001. In order to best develop a method for reattchment, these differing conditions would play a significant role.

The results of the 2001 survey showed that the existing plaster field was not orthogonal but was approximately one inch shorter on the eastern wall than it was on the western wall. Additionally the center medallion was not centered but was west and south by approximately one inch, and finally the distance between the stars around the perimeter was not the same, varying as much as 1/2 inch.

The most threatening condition of the ceiling was identified as the delamination of the plaster from the lath; however traditional acoustical detection of this common condition was found to be subjective and inexact. While the most visually apparent symptoms of the failed ceiling is the cracking which is easily identified through observation, its relationship to delamination is not easily linked. The analytical power of a Geographic Information System (GIS) provided a greater potential for identifying the correlation between external evidence consisting of crack patterns, and blind internal failure linked to delamination. In preparing for plaster conservation treatments that favored minimal intervention, it was necessary to identify those areas that exhibited signs of immanent failure. To ensure the long-term success of this effort, however, it was also necessary to identify areas most in need of continued monitoring. This demanded a more quantitative assessment than was possible in the 1991 survey. It also required an ability to flexibly integrate different kinds of data. To satisfy these requirements, a GIS-based approach was used to map the ceiling in terms of existing and potential threat. The use of GIS was only one aspect of this project yet the results could have the greatest impact on both short term application associated with treatment, as well as long term application associated with monitoring.

The initial efforts involved reviewing data beginning with the 1991 study. This consisted of assessing earlier conditions of cracking and detachment conducted using a traditional acoustic method of tapping on the surface of the plaster and listening to the sound. Additionally in this 1991 survey, a map was created to identify the location of the cracking patterns, which was incorporated onto a rectified photograph of the ceiling. The final result, while good, lacked the precision needed for further analysis.In 2001-02 new data was collected using a plumb bob and two known datum points located at the northeast and southeast corners of the plaster field. Each of the intersections were plumbed to the floor where the distances from each of the two datum points were measured. The intersection of each crack was identified and mapped in AutoCAD® using X, Y coordinates based on the measurements taken from the datum points (Fig. 11). Additionally the Z coordinate or vertical shift out of the theoretical horizontal plane of the ceiling was mapped from these points using a laser level which created a level datum line around the room. Once all of the data was collected and digitally drawn in AutoCAD®, each condition was then imported into ArcView 3.2®. From this point Arcview was used to create regression modeling to identify the correlation between the crack patterns and their variables. Spatial analysis was conducted using three extensions including Spatial Analyst®, 3-D Analyst®, and Geostatistical Analyst® in order to find the spatial structure of the cracks such as density, as well as to create predictive maps to identify the location of potential threats to the surface (Fig. 12).

While the result of analytical mapping is only as good as the data, the use of GIS as a diagnostic tool provided greater clues for new treatment locations and methods. When attempting to protect original ceiling fabric, there is often no second chance, greatly limiting the margin for error. The addition of GIS mapping in this particular case was not an end in itself but rather part of the larger process which required testing of reattachment methods and continued monitoring of the site in order to determine the effectiveness of this modern condition survey method.

The visible plaster of the ceiling was only a small part of the entire ceiling / floor system. Some conclusions, both past and present, have suggested that the variable sizes and patterns of existing cracks may be external indicators of various factors of this entire system, which include the construction and movement patterns of the joists above, the location of lathing fields, as well as the areas of delamination. Cracking and delamination may not always result from the same causes although crack size may be directly related to the areas of delamination. While these cracks represent damage to the plaster ceiling, they also function in a positive way providing control joints which allow the rigid plaster surface to move, helping to reduce the appearance of additional cracks. Unfortunately crack propagation is difficult to limit, and the continued growth of existing cracks may be unavoidable especially where previous damage has not been stabilized. The following observations were made based on the results of the GIS analysis:

- Under force, an existing crack will continue to extend outward until it reaches a limiting edge.
- Under a constant load including gravity, an existing crack will more likely continue to grow before new cracks appear.
- Concentrations of existing cracks are directly linked to the sizes of the cracks, with smaller cracks being closer together, each taking up some of the flex. Larger cracks may be taking the same amount of flex requiring fewer cracks to distribute the force over the same amount of area.
- Areas of the ceiling, which have been compromised and repaired can directly impact the direction of smaller cracking but do not seem to have an impact on the larger cracks.
- The patterns of the vertical deflection of these cracks also show areas where the ceiling has deflected the greatest under its own weight.

ASSESSMENT OF EXISTING PLASTER SYSTEM

The existing conditions of the complete plaster system, which include the original plaster as well as the 1978 treatment, were significant factors when deciding what type of conservation treatment would be the most appropriate. An assessment of these existing conditions was carried out taking into consideration all of the possible variables which may be contributing to the present state of deterioration including installation and composition.

INSTALLATION

The undersized thickness of the original plaster may have played a role in the overall failure of the ceiling. According to William Millar's *Plastering Plain and Decorative* (1897/1998) the minimum thickness for any scratch coat is 3/8". Combined with an additional 3/8" for the most minimal brown coat, as well as an additional 1/16" for the finish coat, the minimum dimension for any plaster ceiling should be 13/16". Since the Great Hall ceiling plaster is only ½", it fails to meet this minmum requirement by 5/16" (Fig. 13). This problem goes beyond the simple fact that the plaster would be susceptible to deflection from the undersized joisting since Millar goes on to state,

> If too thick, [the scratch coat] tends to weigh down the lath-work and is apt to crack; if too thin, the subsequent scratching is liable to cut the coat down or nearly to the laths, thus leaving a series of small detached pats which are unstable, and form a weak foundation for the floating coat, and are a source of cracks, and often the cause of the work falling when subjected to vibration. A thickness of ½ inch [for the first coat] gives the best results[9]

Since the Drayton Hall ceiling plaster is clearly undersized, it is far more susceptible to detachment and cracking in tension with deflection of the joists above.

[9] William Millar, *Plastering, Plain and Decorative,* Donhead Publishing Ltd., Dorset England, 1998, p. 91.

Another contributing factor to the continued deterioration of the ceiling is the method by which the plaster was applied. Plaster is traditionally installed in three coats consisting of a scratch coat, a brown coat and finally a finish coat. Based on cross-sectional examination, the Great Hall plaster was applied in only two layers comprised of a tan scratch coat and a white finish coat. This method, known as *double-up, laid-off or laid-on*, results from the application of the scratch and brown coat consecutively without allowing the standard time for setting of the scratch. Millar refers to this method as *one-and-a-half-coat work* and states that the second coat must be laid while the first is still green, which permits the two coats to amalgamate better.[10] This method is less expensive than the traditional three-coat work, however certain precautions are necessary in order to ensure its success. The brown coat must be applied before the hardening of the scratch, so that the two surfaces can bond together. More significant in the case of the Drayton Hall ceiling is the assurance that the backing, which includes the lath and the joists, be sufficiently rigid that it will not yield under pressure of the trowel and it will not sag under the weight of the combined coats. If there is deflection to any appreciable extent, the keys, which hold the scratch coat to the lath, will probably be broken. Additionally it is not recommended for use on wood, however when applied to wood lath the first coat should be one part of fibered plaster to not more than two parts by weight of dry clean sand.[11] If in fact the plaster ceiling was applied in a *double-up process*, the sagging from the ceiling associated with the under-sized joists could have been a contributing factor to the plaster failure starting as early as its original installation.

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[10] William Millar, *Plastering, Plain and Decorative*, Donhead Publishing Ltd., Dorset England, 1998, p. 101.

[11] Graham, Frank D., *Audels Masons and Builders Guide No. 4*, Theo. Audel & Co., New York, 1958, p. 862.

Another factor which may have contributed to the plaster problems is the dimension of the keys themselves. In some cases the distance between the lathing was smaller than the recommended optimal distance of 3/8” which would have resulted in undersized keys that would have been more susceptible to breakage especially given the lean formulation of the scratch coat. If the mixture itself was too stiff when it was originally made, this also could contribute to the present problems by preventing the proper formation of keying behind the lathing. In the case of the damage located beneath the second floor hearth, the problem was unique resulting from the lack of undercuts on the lath in the location of the fireplace header. Poor installation design was further exacerbated by the lean formulation of the scratch coat and the high clay content of the binder analysis resulting in a friable weak plaster (see below).

COMPOSITION

Samples of original ceiling plaster including the scratch and finish coats were analyzed using the fallen material from the southeast corner. Techniques included gravimetric analysis, reflected and transmitted light microscopy, Fourier Transform Infrared Reflectography (FTIR), x ray diffractometry (XRD), scanning electron microscopy (SEM) with x ray spectroscopy (EDS), and thermogravimetry (differential thermal analysis-DTA).

Microscopy identified the basic stratigraphy of the samples as described elsewhere and a predominately quartzitic aggregate . Instrumental analysis was performed to identify chemical composition. SEM-EDS revealed the presence of calcium, iron, magnesium, aluminum and silicon in the brown scratch coat, suggesting a lime and clay matrix. FTIR and XRD identified calcite and kaolinite in the brown scratch coat and calcite and gypsum in the white finish layer. No calcium silicates were found suggesting a non-hydraulic binder. Instrumental analyses confirmed both visual and gravimetric analysis of the ceiling plaster as a typical lime, clay and sand scratch coat with animal hair followed by a gypsum and lime finish coat with little to no aggregate. This is completely in keeping with the technology of the period and the observed performance of the plaster layers. Atypical was the high amount of clay found in the scratch coat, probably added as an extender, which would account for its high friability and very low tensile strength.

1978 INTERVENTION

A review of the 1978 treatment suggests that while the overall approach may have been excessive in its extent, it has been relatively successful. This treatment method, also used at Philipse Manor in Yonkers New York in 1971, dates back at least as far as Millar (1897) who outlined a very similar process (Fig 14).[12] During early visits to the site in 2001, guides were overheard commenting on the fact that the 1978 treatment had been viewed at the time of installation as being a final solution to the problem; however it was later apparent that that treatment had not eliminated continued plaster failure.

Areas of the ceiling where plaster had been lost or removed prior to our treatment in 2002 allowed us to examine the results of the 1978 treatment. The fundamental goal of the 1978 treatment was to create continuous reattachment to the back side of the historic plaster allowing it to remain in place. Some early discussion suggested that this approach was not completely effective because it had not taken into consideration the blind voids that likely existed as a result of the original plaster pulling away from the lath. The high viscosity of the plaster of Paris and the low force of the pouring method would not have allowed the treatment to fill these voids. Contributing to this was the fact that the water that had been mixed with the plaster of Paris may have been absorbed prematurely into the dry lathing and friable scratch coat further reducing the extent to which it had flowed. Based on photographs taken after the removal of temporary stabilization in the fall of 1978, damp stained areas on the exterior surface of the plaster suggest that

[12] William Millar, Plastering, Plain and Decorative, Donhead Publishing Ltd., Dorset England, 1998, p. 273.

moisture contained within the poured plaster of Paris weeped through the original scratch coat and plaster introducing possible additional problems to a compromised ceiling.

Areas inspected in 2002 where the lathing had been exposed from below, showed that the poured plaster in fact did not flow evenly throughout all of the voids in the ceiling (see Fig. 8). The poured plaster had flowed between the lathing plaster resulting in the creation of new keys. In addition there was concern that new detachment may have occurred since the 1978 treatment due to high friability of the older plaster. As a result it was felt that even with the success of the earlier treatment, areas where voiding could be significant should be treated. Since the new treatment would require pre-consolidation, intended to strengthen the older brown coat, the newer treated areas would improve the longevity of the ceiling by assuring that no additional breakage would occur at the interface. In traditional lath-plaster ceilings, bonding is the result of mechanical keying with limited attachment between the plaster and the underside of the lathing. In addition to re-establishing broken keys, the injection of an acrylic adhesive below the lathing would have resulted in an increase in the total area of plaster attachment through adhesive bonding.

TEMPORARY STABILIZATION

A decision was made early in the project that some form of temporary stabilization was needed during the structural retrofit above in order to secure both the damaged and sound plaster before treatment was conducted. Knowing that stabilization was required, it was quickly understood that the function of this stabilization was not to hold the entire floor system in place but instead simply to prevent plaster from further detaching from the lath or falling to the floor. The strength of the support system needed only to be based on the weight of the 5/8” plaster ceiling and in almost every case did not need to address the issue of catastrophic failure from large scale detachment.

As had been identified in the documentation phase of the project, the problems associated with the ceiling were not consistent across the entire surface and as such not all areas of the ceiling needed to be stabilized. Identifying locations for stabilization as well as determining a method for fabricating the stabilization was based on a set of parameters which included the following:

- Present known condition of the plaster
- The type of work required to install the flooring above
- Continued access of the first floor for public tours
- Cost and ease of installation

Using the 1991 condition assessment, four major areas had been initially identified and specified for stabilization; however information gained from the 2001 survey indicated additional areas where potential problems might occur. Additionally the stabilization was to be focused only on the area where new flooring was to be installed. Using GIS assessment, which showed a direct connection between plaster conditions and failure, it was decided that a greater distribution of stabilization would be necessary. Based on discussions with the engineering team, it was understood that the contractors installing the floor would not use nails but rather screws thus eliminating heavy impact of hammering which was seen as a potential problem for the weakened plaster.

While there was a possibility that ceiling fragments could become detached from the associated work with the floor installation above, the potential for catastrophic failure was virtually non-existent, and as such the need for stabilization was not seen as a method to prevent the ceiling from falling but instead as a way to eliminate vibration. Vibration was presumed to be a contributor to the existing detachment. While the use of screws instead of nails would eliminate vibrations associated with hammer percussion, movement associated with the installers as well as the potential for dropping tools and equipment presented potential vibrations which also needed to be addressed. Learning from the damage created during Hurricane Hugo, additional measures were taken.

While the conditions of the ceiling ranged from complete loss to structurally sound plaster, it was decided that identifying areas for stabilization should be based on the degree and extent of detachment. The first and most severe condition was plaster which had fully detached but was still in place. This condition was observed around the edges of complete loss and in isolated areas of total detachment. It was understood that in the latter situation, the failed plaster would most likely need to be removed in order to properly reattach it, however reinstalling these sections of plaster was far more desirable than replacing them with new plaster. This occurred in two sections of the ceiling, beneath the second floor hearth and in the southeast corner. The second plaster condition was those areas of plaster where blind detachment had been identified from sounding.

From this classification, eight areas were temporarily stabilized and in each case the goal was three-fold (Fig. 15). The primary function was to reduce the possibility of fragile plaster detaching due to vibration. Secondary functions included keeping areas that might become detached in their proper location so that they could be easily identified, as well as preventing areas which might become detached from falling and breaking. Since the Great Hall was to remain open for tours, the design of the stabilization system needed to be minimal, reducing the amount of obstructed space in the room.

The temporary stabilization also needed to be easy to remove and reinstall, and in fact was taken down and reinstalled for a fund raising event. Additionally the choice of the materials for constructing the system was based on cost and availability as well as ease of construction. All materials were purchased locally and each unit was built on site using basic construction equipment. The system was designed to be adjustable to address the variations in room height between the floor and ceiling. Since both the floor and ceiling were not level or coplanar an adjustable unit was critical.

Eight stabilizing units were built; each unit consisted of four telescoping legs which supported a 4' X 6' sheet of 1/8" padded lauan plywood (Fig. 16). To create each unit, legs were manufactured using 4' lengths of dowel with a 1" diameter. In order to create the telescoping feature for the legs, 10' lengths of rigid conduit were purchased which had a 1" interior diameter allowing the conduit to slip over the top of the dowel. At the base of each section of conduit two small holes were drilled which allowed screws to be driven into the dowel, once the leg had been extended. This ensured that an extended leg would remain in place. 16" square bases were created using oriented strand board (OSB) to keep costs down. To the center of each of these bases was attached the dowel using a 2" X 4" X 4" plate with a one" hole drilled in the center into which the dowel was inserted.

A padded 4' X 6' sheet of luaun plywood was placed against the ceiling to provide cushioned support. This in turn was covered with Tyvek® paper to reduce the possibility of staining or discoloration, which might be transferred from the wood or the padding to the white plaster surface. At four locations on the lauan sheet, short 10" lengths of dowel were attached in a similar fashion as the longer 4' lengths on the bases.

By inserting these short lengths of dowel into the conduit at the top, the entire 4’ X 6’ sheet could be easily raised into place by sliding the conduit upward over the lower doweled bases. The advantage of this simple design was that each leg had an infinite number of potential locations which allowed for fine adjustment. Each sheet was raised into place and lightly pressed to the surface so that the padding was compressed evenly across the plaster surface. The raised sheets of padded lauan were intended to support the plaster in place as well as reduce the vibration from above by distributing it through the 1” layer of foam padding.

Manufacturing took the longest time requiring two people working for three days; however installation was rapid taking only a matter of two hours to install all nine panels. These panels were very effective in that no plaster was lost during the floor reinstallation. Other significant features of this stabilization method was its low cost as well as its ease of installation. An additional benefit was that each telescoping leg was later used with a padded cushion during the treatment phase to introduce isolated pressure to the treated areas while the grout had time to set.

2002 TREATMENT PROGRAM

Treatment began in June of 2002 after an extensive program of analysis and testing. Since it had been determined early in the assessment phase that treatment would not be performed on the entire ceiling, the first phase of intervention involved identifying the locations where treatments would be conducted. While initial areas had been specified, a final determination was not made until after careful inspection on site. The decision about these primary areas involved a comprehensive interpretation of the ceiling using the results of the 1991 survey, the 2001 GIS analysis, the review of the 1978 treatment, and an understanding of the properties of the preferred injection grout method based on the mechanical testing phase of the 2002 research.

In 1991 following the original condition assessment, three areas were identified for treatment based on the severity of the mapped conditions. These areas included 1) an easily identifiable location below the second floor hearth on the southern wall where the plaster field was clearly the most compromised; 2) a location between the center medallion and the north wall and 3) a location between the center medallion and the west wall. The 2002 GIS analysis provided a new way to understand the areas for potential treatment based on observed correlations between cracks and detachment, allowing intervention to be more selective. By looking at the more clearly defined areas of potential threat from the 2002 GIS and by turning to the information related to the 1978 treatment, we were able to build confidence in the potential results of our selective injection grouting. The introduction of newer diagnostic technology has provided evidence which allowed more selective treatments with greater confidence.

Understanding the existing conditions and creating a set of treatment criteria to guide intervention was a major part of developing a comprehensive conservation plan. All components of the ceiling were considered including joisting, lathing and plaster. While all of the work planned during the present conservation phase, including the structural retrofit by Sillman Associates, would help to extend the life of the ceiling, it was not a cure-all to the problems. The undersized joisting would still be undersized, the lathing would still be too close together, the brown coat would still be too lean a mix, and cracking would most likely still occur. As such, the best approach to treatment would be a conservative one which would treat the ceiling conditions location by location. The intervention carried out in 1978 treated the entire ceiling as a single entity. Our approach would address the ceiling knowing that not all areas required equal intervention. In this way "smart" minimal intervention could be achieved.

Another limitation was that no treatment could be carried out from above. Although the second story floorboards had been removed, the 1978 treatment which involved pouring plaster of Paris into the pockets between the joists eliminated any possibility of viewing or treating the ceiling from the second floor. This meant that all new treatments needed to be conducted from below. In order to limit the amount of alteration to the surface, any penetration through the visible surface of the plaster was to be limited to the "damaged" areas of the plaster or the open cracking.

The GIS had identified the possibility of threat which became the roadmap for treatment. The areas of greatest threat were defined as being the most likely areas of detachment and cracking. The preferred method for treatment was based on Morgan Phillips' earlier work on plaster reattachment that included different injection formulations as outlined in two seminal articles he authored in the 1980's.[13] These mixes

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[13] Morgan W.Phillips, "Experiences in the Use of Acrylic Plaster Adhesives" in *Case Studies in the Conservation of Stone and Wall Paintings. Preprints of the Contributions to the Bologna Congress , 21-26 September 1986*. Ed. N.S. Brommelle and Perry Smith. The International Institute for Conservation of Historic and Artistic Works. London and

used the same basic four ingredients consisting of two acrylic emulsions (Rhoplex MC-76, the stronger component originally designed as a masonry bonding agent and Rhoplex 1950, the more flexible component originally designed as a binder for elastomeric sealants), water and a thickener (Acrysol ASE-60) to control viscosity and flow. By varying the quantities of the acrylic emulsions , Phillips was able to develop two different mixes for varying situations. Filled and unfilled options for each of these two mixes were designed to provide for filling both small gaps where the distance between the surfaces was less than 1/16 of an inch as well as large gaps where the distance between the surfaces was much greater. An important aspect of the current study was the mechanical testing of some of these formulations alone and in combination with wood and original ceiling plaster (Figs. 17, 18 and 19).

Based on the research which had already been conducted by Phillips, the only quantitation testing carried out in 2003 was mechanical bond strength.[14] The results of the mechanical testing showed that while the two formulas (flexible and non-flexible) possessed sufficient bond strength for the treatment, they differed in strength based on whether they were filled or unfilled. A matrix of sample assemblies was designed to allow for testing of bonding strength for each possible formulation in conjunction with the various combinations of adherends. These combinations included scratch coat to scratch coat (Fig. 17), scratch coat to finish coat (Fig. 19) and scratch coat to wood lath (Fig. 18). A decision was made to run the tests only on original materials gathered from the site, limiting the number of samples which could be tested. Although only 17 combinations were possible with the limited amount of original material and not all the tests were successful, the results of the mechanical testing were significant enough to warrant further study.

Adhesives for the reattachment of loose plaster. *APT bulletin*, **12**, no. 2. 1980, pp. 37-63,

[14] Testing was carried out at the Laboratory for the Research on the Structure of Matter (Upenn) under the guidance of Dr. Alex Radin.

Both formulations provided adequate bond strength between adherends greater than the cohesive strength of the consolidated scratch coat. In most cases the comparison of one combination of bonded adherends to another (using the same formula) resulted in similar performance; however there were significant differences observed when comparing the filled to the unfilled versions of the flexible formula. The filled formula, which consisted of the same resin binders as the unfilled formula, also included fluid coke, microspheres and lime as the aggregate and shrinkage compensators. This formula revealed a higher bond strength and displayed less elasticity (higher modulus of elasticity) than the unfilled formula. While fillers were necessary to control shrinkage, they also significantly modified the modulus of elasticity when compared with the unfilled flexible formulation.

COMPLETE REATTACHMENT (Fig. 20)

The first areas to be treated were two large sections of the ceiling where damaged plaster had been completely detached exposing the lath beneath. These areas allowed for the use of the unfilled mixture since the plaster being reinstalled was in direct contact with the surface of the lath. In order to treat these areas, any loose plaster which showed signs of imminent failure was removed and numbered for later reinstallation. Once this loose plaster had been removed, the lathing itself was thoroughly cleaned using a stiff brush to remove loose dust and debris, at which point the lath was carefully inspected to provide a better understanding of the properties of the lathing system, the causes of failure, and the impact of the 1978 treatment. The first area treated was the section on the north wall below the second floor hearth. In this particular case it was determined that the failure was not associated with the same causes of failure found in other areas of the ceiling. This particular area of damage was aligned with a paired sister joist which had been originally installed to support the weight of the fireplace hearth stone above. This joist was unique to the ceiling because it ran parallel to the lathing. In cases where lathing runs parallel to joisting, the lath which comes in contact with the joist needs to be undercut at an angle in order to allow for keying of the plaster to occur. In this section of the ceiling the lathing was not undercut resulting in plaster which was poorly keyed and held in place only by the strength of its bond to the wood as well as by the overall surface strength between the two nearest points where keying occurred. The failure in this area was inevitable and could easily have occurred in any ceiling system.

All loose pieces in this area which had became completely detached, were held in place by the pan that had been installed earlier by the Drayton Hall staff. This pan was carefully removed with loose pieces inside. Any additional fragments of plaster around the area which exhibited signs of failure were also removed. Approximately 20 fragments of plaster were carefully laid out and numbered in order to provide for easy installation (Fig 20a). After the lathing was brushed clean, a 10% solution of Acryloid B-67 dissolved in mineral spirits was applied over the exposed lathing. Each fragment of plaster was also thoroughly brushed clean and consolidated with B-67 in order to increase the cohesive strength of the friable brown coat (Fig. 20b). Following the consolidation of the surfaces of each fragment (allowed to dry over night) a thickened coat of the unfilled acrylic mixture was brushed onto both the backside of the plaster as well as the underside of the wood lath surface (Fig 20c). The thickener for the treatment was created by adding a small amount of ammonia to Acrysol ASE-60 which produced a clear inert gel similar to the consistency of pudding. This gel could be added as needed to increase the viscosity and tack of the mixture. Since all of the work on the ceiling was conducted from below, the effects of gravity made this thickener extremely valuable by helping to limit the amount of dripping and sagging which could occur. The earliest attempts to reattach these fragments without the thickener proved impossible. With both surfaces coated, each loose piece was then installed in its original location and supported using a telescoping leg with soft padding on the end (Fig. 20d). These supports were reused from the earlier temporary stabilization and were left in place over night allowing the emulsion to set. Once all of the fragments were well adhered and the supports removed, all of the cracks around the newly installed pieces were infilled with Dap® lightweight jointing compound. While the end result is not invisible from the ground, the infilling minimizes the visually jarring impact of the dark cracks against the white ceiling (Fig. 20f).

Although the adhesion in the hearth area was successful, one difficulty resulting from the 1978 treatment was our inability to position the reapplied plaster in a uniform plane with the rest of the ceiling. At a point in the history of the ceiling prior to the 1978 treatment the lathing in this area had become loose (possibly a result of corroded lath nails associated with water leaking through the roof) and had pulled away from the surface of the joist to which it had been attached. The 1978 treatment of the ceiling from above caused the gaps between the lathing and the joists to become filled with plaster of Paris which, once set, eliminated the possibility of this lathing being renailed in plane with the other laths. This problem was then telegraphed outward to the newly reattached portions of plaster resulting in an uneven surface.

A similar treatment was also carried out in the southeast corner which was damaged during Hurricane Hugo (Fig. 21). Due to the extent of the damage resulting from the impact of the plaster on the floor below, most of the fragments were too small to be effectively reinstalled and were therefore used for the 2001 testing program. This section of the ceiling required a similar treatment to that applied to the area under the hearth because a large amount of the plaster immediately surrounding the area of loss was loose and threatening to fall. Fragments of this loose plaster were removed and then reinstalled following the same procedure outlined above. In addition to the damaged field plaster, a decorative cast rondelle and some of the perimeter stars were lost during the accident. Since all of the plaster which had fallen from the ceiling had been carefully boxed and stored by the Drayton Hall staff, fragments of the damaged rondelle were carefully fitted back together by the plastering team and later reinstalled. The stars which were still in good condition were reinstalled at the same time the other original decorative elements were reinstalled.

PRECONSOLIDATION AND INJECTION GROUTING (FIG 22)

The next phase in the treatment involved injection of the filled flexible acrylic emulsion formulations to reattach areas of the ceiling which were identified as detached but were still in place. Once cracks and their adjacent areas had been identified for injection, holes were drilled at an interval of approximately ½" using a 7/64" drill bit (Fig 22b). For each crack, drilling was begun in the center of designated lengths instead of at the ends. The purpose for this was to ensure that only truly detached areas were injected rather than the entire crack. As each consecutive hole was drilled in a given direction along a crack, the amount of space within the gap between the plaster and the lathing was monitored using a simple technique of intuitive sensing. When drilling through the plaster resistance was noted. Once the bit exited the top side of the plaster and entered the void, it traveled with no resistance until it came in contact with the lathing and poured plaster above. As the drilling progressed along the length of the crack, the distance the drill traveled unhindered in this gap changed, reflecting the size of the void between the finished plaster surface and the lathing. This gapping continued to shrink until it disappeared completely. At the point where this gapping ended, the drilling was stopped in the present direction and then reinitiated from the first hole drilled, traveling in the opposite direction along the crack.

As one team member carried out the drilling, the other member cleared dust and debris with compressed air and consolidated the friable brown coat with a 10% solution of Acryloid B-67 and mineral spirits using an aerosol spray bottle (Fig. 22b and c). During the testing phase, mineral spirits had been identified as the only solvent for the B-67 which would not result in staining of the ceiling's finished surface. In order to introduce the consolidant to the voids, an aerosol was created using a pressurized bottle. Attached to the tip of this bottle was a 6" flexible extension tube which could be inserted into the void through the drilled holes (Fig. 22d). The flexibility in the tube allowed us to introduce the consolidant in all directions in an attempt to maximize the coverage. By using an aerosol we were able to consolidate with a lower controlled volume at higher pressure, thus increasing our range of coverage as well as reducing the chances of over saturation. Once these areas were consolidated, they were allowed to dry over night. Drilling of the holes was carried out in phases in order to ensure the completion of treatment during the available time period. The first set of holes drilled for treatment were in the most threatened areas of the ceiling. These holes were drilled and consolidated the first day followed the next day by the injection of the grout.

Due to the size of the voids encountered during the drilling of the injection ports, all of the injected repairs were carried out using the filled formula to compensate for shrinkage of the grout. All acrylic mixes were created just prior to injection and were used for no more than one hour at which point any remaining mix was discarded and a new batch created. Due to the color of the fluid petroleum coke, the filled formula was dark grey (unlike the unfilled version), raising concerns of possible staining on the finished surface of the plaster. Early results showed that staining could easily result from ejected material and although the microspheres were intended to reduce the chances of backflow once the material was injected, pressure from inside due to over injecting was a common occurrence. Although the rate of injection was controllable by varying the amount of pressure applied to the syringe plunger, over-injection was common due to an inability to see into the gaps to determine their overall size. It was also found that over-flow through neighboring holes during injection was common and desirable as well to ensure complete void filling. Finally, the pressure that was added to the plaster surface once the injections were finished also produced a back-flow resulting from the slight decrease in the size of the filled voids. Similar to the effects of a garlic press, small strings of material would be pressed out of the drilled ports once the pressure was introduced. Although this backflow was seen as a good indication that the voids were well filled, it added to the staining concern. A final decision was made to add acrylic thickener in an attempt to reduce this staining. Different versions of the mix were tested until a final mix the consistency of gel toothpaste was found. Although material was still ejected out through the drilled ports, due to the higher viscosity, the ejected material could easily and quickly be removed with a small palette knife before it had a chance to stain the surrounding white finish plaster.

Injection was done using a 20 cc veterinary syringe with a stainless steel canula (Fig. 22e). Obviously the smaller the drilled port the less apparent the fills would be from the floor. The final choice of a 2-inch long metal canula with a 3/32 inch diameter was based on the size of the flexible tube which had been used for the consolidant injection. Tests were run using flexible plastic canulas and while the early tests with the unthickened mix proved promising, the results with the thickened mix were poor because the canulas had a tendency to clog. Although early impressions suggested that a flexible canula could provide better coverage, in the end the team agreed that the results gained from the non-flexible canula were extremely successful. Injections conducted near one of the areas of exposed lath allowed for a cross sectional view of the process and the evidence showed that the mix had all of the desired physical properties including low shrinkage and good flow under pressure (thixotropy).

Just prior to the actual injection of the filled emulsion grout, each hole was pre-wet with a 5% solution of the unfilled adhesive in order to improve the chances of a 100% bond. This pre-wetting presented similar problems found in the consolidation where control of the liquid was often difficult. Because the liquid had a low viscosity, it was not uncommon for it to drip back out of the hole once it had been injected. For the application of the pre-wetting agent a spray bottle was used with success.

The goal was to make sure that all areas drilled could be treated in the overall allotted time. Reserving two days for back filling and clean-up, the injection grouting was carried out in stages. Three separate phases of drilling, consolidation, pre-wetting and injecting adhesive were carried out on the surface of the ceiling, with each consecutive phase addressing identified areas of lesser concern. In the end over 1000 holes were drilled and injected. Based on the weight of each material and the overall amount of material injected into the ceiling it was determined that no more than five pounds of dry weight was added to the ceiling.

Once all of the holes had been injected with the adhesive grout, each one had to be properly cleaned before it could be filled. Each of the holes had a small glossy halo from the pre-wetting agent as well as a small dark ring around the edge resulting from the filled injection grout. In order to remove the halos, a light sanding of the surface was carried out using 220 grit sand paper. A Dremel® was then used with a small cone shaped grinding bit to removing the remaining black rim (Fig. 22f). After the light sanding it became apparent that a slight whitening of the surrounding surface had occurred resulting from removal of existing surface soiling and the ceiling's limewash. In order to reduce the visual impact, crack areas were lightly cleaned using Wishab® chemical sponges (Fig. 22g). Although a complete cleaning of the ceiling was not carried out, enough cleaning was done to reduce the visual impact of the sanded areas around each of the holes and cracks. With all the holes properly cleaned, each one was filled using a small amount of Dap® brand light-weight jointing compound which was mixed with equal parts of microspheres to make a drier, weaker fill (Fig. 22h). In addition to the holes, several of the larger cracks were filled as well in an attempt to reduce their visual impact from the floor and provide additional support. The advantage of these filled cracks is that they can now act as "tell-tales" helping to show movement resulting from the introduction of live load to the second floor Great Hall for the first time in more than 10 years. Should these fills crack over time from plaster movement, they can easily be replaced. Finally, loose and removed cast ornaments were reattached with the unfilled adhesive formula (Fig. 22e). All 2002 injection treatments were mapped for future reference (Fig. 23).

CONCLUSIONS

While the overall treatment was deemed successful upon completion, it is critical that all the parties involved with the continued maintenance of the site recognize that the work which was carried out is not a final solution. Based on all of the evidence gathered during the 12-month period of the project, it is clear that this ceiling will continue to move. The original plaster was poorly formulated and installed. While the treatment has clearly achieved its objectives by reattaching the damaged areas of the plaster ceiling, it has not corrected the inherent problems. It is impossible to know if the reintroduction of live-load in the second floor Great Hall will continue to adversely affect the ceiling since there was never a comparative conditions assessment carried out during the period in which live load was present. The 1991 conditions assessment was conducted the same time the bridge was installed to eliminate the live load from the room. The new 2002 assessment clearly shows that little additional damage occurred in the intervening 10 years but this comparison is not a fair assessment of the overall changes that this ceiling could endure now that visitors have been reintroduced to the upstairs. As such it is critical that the ceiling be carefully monitored during the course of the next several years as the ceiling takes the impact of new live load. In the event that any new cracking occurs, the option to reinstall the bridge should be seriously considered. In addition it is advisable that the ceiling undergo a condition assessment using the new GIS data within one year and at regular intervals for the remaining history of the house.

APPENDICES

APPENDIX A

REVIEW OF PAST DOCUMENTATION AND ASSESSMENT

ROBERT A. SHOOLBRED
REPORT ON THE STRUCTURAL ANALYSIS OF DRAYTON HALL FOR THE NATIONAL TRUST FOR HISTORIC PRESERVATION
MARCH 5, 1977.

This brief report is a basic condition survey of the entire building with a focus on structural integrity. It clearly states that the 3” X 10” joists spanning the entire 30 feet spaced approximately 17” on center are undersized, yielding a live load capacity of only 14.2 pounds per square foot. The large span to depth ratio of these members has caused excessive deflections in this room. Additionally the report shows the numeric values for live load capacity for the undersized joists.

Unfortunately the work which was done using the available numbers would not have included the additional weight of the poured plaster of Paris or the steel angles which were not installed until the following year.

JOHN G. WAITE

AN EVALUATION OF THE CONDITION AND PRESERVATION POTENTIAL OF DECORATIVE PLASTER CEILINGS AT DRAYTON HALL, CHARLESTON, SOUTH CAROLINA,

MAY 2, 1977

John Waite's report was the first study dedicated specifically to the plaster ceilings in Drayton Hall. For the Great Hall he provides a general description of the plaster and wood system as well as offering explanations about the cause of the problems associated with the deterioration. He states:

> There are major problems on the upper surface of the ceiling. The plaster keying has sheared off in many locations, probably as a result of the excessive deflection of the floor framing. Furthermore, the original plaster mixture may have been insufficiently strong in tension. There are many indications in the form of straight cracks running north-south that the keying has failed and that the plaster ceiling is falling away from its lath. Large sections of the ceiling near the medallion and the existing patch, as well as near the mantel end of the room have been loosened and may fall at any time.

Unfortunately this report provides no existing condition survey or any analysis. This report concludes with a set of recommendations for the repair of the ceilings including the following guidelines for the stabilization of the Great Hall ceiling.

- Support ceiling from below with plywood, carpet padding, and wood struts
- Number and carefully remove each floorboard by cutting through the tongues
- Remove all plaster debris, broken keying, and dirt using industrial vacuum cleaners and soft brushes
- Correct structural deficiencies of the floor framing system
- Refasten lath to joists using glue blocks and an intermediate structural system of adjustable aluminum angles (Similar to Philipse Manor method)
- Coat existing wood lath with approved modern bonding agent
- Install wire mesh reinforcing and pour a new layer of plaster to bond existing plaster to the lath
- Reinstall floorboards

These recommendations resulted in the closing of the second floor to all persons effective 3 May 1977 in order to prevent further deterioration. The treatment recommendations outlined in the report were also used for the reattachment effort carried out in March and April of 1978.

GRANT NO. 90-75-00133-00
HERITAGE CONSERVATION AND RECREATION SERVICE DEVELOPMENT PROJECT
COMPLETION REPORT
(DATE UNKNOWN)

This report is the completion notes for the ceiling restoration and consists of a series of images taken by J.M. Garrison illustrating the process. Although no written information is present for the Great Hall ceiling, the report outlines the process carried out in the Ionic Drawing Room ceiling. An area of approximately 10 square feet of lath was uncovered directly over the critical section of the ceiling and the section was stabilized using the same system of bonding agent, hardware cloth and plaster as in the Great Hall. Glue blocks were used to reinforce the connection of the lath to the joists using an adhesive sealant (Scotch Weld #5230) rather than steel angles as in the Great Hall. Although it is not known which bonding agent was actually employed, the specifications for the project stated using Plaster-Weld.

HANOVER ENGINEERS

LETTER TO MR. BIERCE

OCTOBER 1, 1987

Hanover Engineers submitted a proposal for reinforcing the floor framing on October of 1987 but the proposal was rejected because it would require too much intervention into the building's historic fabric. The proposal states,

> In a previous attempt to preserve the ceiling, the joists were reinforced by bolting angles to the sides of the joists near the top and bottom of the joist. With proper bolting, this method would have been effective in increasing the moment of inertia of the joists. However, for some reason (which is not clearly provided) possibly the slip on the bolt holes through the wood, the repair has been less than effective. Additionally, 1" of gypsum plaster was cast on wire mesh immediately above the ceiling, leaving only 9" maximum effective structural space between the flooring and the ceiling.

The proposal suggested adding two steel girders in the floor and two 4" pipe columns in the wall which would correct the original construction flaws.

CHARLES EDWIN CHASE AND KEVIN MURPHY

DRAYTON HALL: ARCHITECTURAL AND DOCUMENTARY RESEARCH REPORT

1988

This is an extensive 300 page report which covers both historic research of the family and the building as well as a description and preliminary survey of the condition of the building. The report states "The fracturing of the plaster is evident in the center modillion and above the fireplace in the south wall. Repairs have been made above the fire place at an unknown date." The only other significant reference to the Great Hall plaster ceiling is contained in Chapter 4-Procedural Analysis for Stabilization where the authors write,

> The circa 1860 decorated plaster ceiling shows signs of initial stages of failure throughout. The stresses caused by deflecting floor joists above have caused the ceiling to crack. From x-ray analysis

> it has been determined that the bonding of plaster to lath is in fair condition and may require additional bonding agents. Measures to stabilize this ceiling should be concentrated on the strengthening of the second floor joists. If at all possible, the original joists should remain intact and be stiffened in place with steel flitch plates bolted to either side of the joists.

This report was completed 10 years after the work carried out on the ceiling in 1978 by the Restoration Workshop of the National Trust for Historic Preservation, and yet the suggestion is the existing stabilization system was still unsatisfactory and that new steel was required.

NATIONAL TRUST FOR HISTORIC PRESERVATION COLLOQUIUM

APRIL 27- 29, 1990

Although no formal report exists on the findings of the colloquium, the most significant outcome from this meeting was a mutual agreement that the Great Hall ceiling needed to be properly documented and its conditions recorded before any further work was executed.

FRANK G. MATERO, ET. AL.

DOCUMENTATION AND CONDITIONS SURVEY, GREAT HALL CEILING, DRAYTON HALL, SOUTH CAROLINA

DECEMBER 6, 1990

The report carried out by the ACL of the University of Pennsylvania was in response to the request from the colloquium to conduct a comprehensive recording including a conditions survey of the Great Hall ceiling prior to any additional treatment. This report was the first comprehensive survey to identify existing conditions in an attempt to identify the causes of deterioration. Additionally the report included analysis of the construction history and past stabilization of the room and ceiling and its role in contributing causes to current problems. This report concluded that the efforts carried out by the Restoration Workshop under the guidance of Jack Waite were largely successful in meeting the stated objectives.

> At exploration Zone No. 2 the authors observed a 1/8" cavity remaining between the plaster and the lath. Surfaces within the cavity had been stained pink, indicating penetration of the bonding agent; and, although the cavity had not been completely filled by the pour of plaster of Paris, enough of the liquid plaster had entered the cavity to effect a reattachment of the plaster to the lath. Although tapping in this area indicated the presence of other unfilled spaces, most likely between the plaster and the lath, the plaster itself felt solid and firmly bound to its substrate, suggesting that reattachment had been achieved through bridging of the detachment space without its complete obliteration.

This report also included a graphic conditions survey and defined conditions and created a glossary which could be used in later condition assessments as a tool for comparison and monitoring.

The problem with the structural retrofit of steel is addressed here for the first time as well based on conclusions provided by consulting engineer G. Eric Johansen P.E.. The conclusions suggest that one of the issues which could be contributing to the possible continued failure of the ceiling is the addition of 4500 pounds of steel to a weakened structural system. "The added dead load has certainly increased the deflections of the joists through creep that has occurred in the time interval since the installation of the steel." Additonally this report shows that the Shoolbred report specified that the angles be attached with 3/4 inch diameter bolts, however instead they were attached with 5/8 inch diameter bolts inserted into ¾ inch diameter holes. The effect of these oversized holes is that the angles are not activated until the joists deflect and engage the bolts. Perhaps the most important contribution from this report is the comment about the two different treatments carried out somewhat independent of each other.

> Both the Shoolbred and Waite studies and the treatments that resulted from them cannot be faulted because they achieved their immediate goals. It is nevertheless to be regretted that the two studies were not better coordinated, for in the separation of the two projects an opportunity to address and perhaps remedy the cause of the ongoing deterioration of the Great Hall ceiling may have been missed.

G. Eric Johansen's report suggests that Shoolbred's effort in fact did not fully accomplish its objective and recent data collected during the 2002 treatment suggest that Waite's solution to the problem may have contributed additional problems to the ceiling system. These may be the most important issues related to the continued preservation of Drayton Hall. Without proper knowledge of the ceiling-floor system, both past and present problems cannot be properly assessed. Proper background research, documentation, and monitoring are critical.

PATRICIA GROSSI AND JANET MELLEN

SYSTEMS 470 PROGRESS REPORT:

THE PRESERVATION OF DRAYTON HALL- AN AMERICAN TREASURE

DECEMBER 9, 1991

The report completed by students of G. Eric Johansen was an attempt to quantify the problems associated with the structural system of the floor. Unlike the report carried out by Shoolbred in 1977, the information reflects the present conditions including the added weight of the plaster and steel . One of the most significant points addressed was the impact of the additional weight associated with the poured plaster and addition of steel angles to the sides of each of the joists. "This extra weight (6500 pounds based on Johansen's calculations) has decreased the buildings lateral resistance to earthquakes. As G. Eric Johansen has pointed out, even though the extra 6500 pounds is only an increase of approximately one percent in the weight of the whole structure.

The impact of the added steel is addressed in this report. "Without the steel angles, the floor has a vibration frequency between three and four. With the steel retrofit, the frequency should be in the range of fifteen or above, with a minimum of ten. This low value causes the floor to have a "trampoline effect" when a person of average weight walks across it."

Section seven of this report addresses the analysis of the existing retrofit which perhaps has the greatest impact on the present state of the ceiling. This report states that "upon review of the Shoolbred structural report, we have determined that his analysis is lacking in the following:

- It is evident that the report did not consider the deflection (stiffness) criteria of the 3 X 10 joists
- Mr. Shoolbred provided very "cheap" loading conditions, carrying out the loads to the hundreds place, instead of rounding up to the nearest five or ten. For example, he states that the 1-inch flooring load is 3.33 psf, instead of rounding up to the nearest 5 psf as done in practice
- Nowhere does the report consider the vibration characteristics of the floor

- Nowhere does the report consider earthquake or hurricane loads
- The report did not address the issue of how the steel angles should be affixed to the joists and the potential damage that the joists would sustain during the intermediary steps of installation
- The report did not consider the extra live load that this building must sustain due to its increased daily traffic
- Most importantly, the report never considered what adding 4500 pounds of steel to the ceiling would do to the structural characteristics
- Additionally all the calculations were preformed under the assumption that the steel retrofit would be installed correctly

GEORGE FORE
DRAYTON HALL, CONDITIONS ASSESSMENT
MAY 1996

George Fore's report from 1996 dedicates only 1-1/2 pages to the issues relating to the ceiling condition, however he states that,

> The analysis of the plaster ceiling's condition, its reaction to movement in the ceiling joists, and suggestions for reinforcement and corrective measures are being considered in the environmental and conditions analysis study of Drayton Hall. Although it is too early in the conditions study to make recommendations, general impressions of the ceiling's condition suggest limits to the level of conservation intervention.

The reference to the environmental and conditions analysis study relates to the comprehensive report prepared by Ford, Farewell, Mills and Gatsch Architects for which George T. Fore was a consultant on the team. Although Fore states that it is too early to make recommendations, he states that limiting visitor loads to the perimeter of the room as it was before is one option to consider with a two level approach to stabilization of the plaster panels. He also states,

> The ceiling area outside the perimeter walk could be further isolated from deflection and vibration by making the flooring discontinuous between the walk path and the remaining floor. The flexure of the ceiling system is such that all repairs or reinforcement of the plaster ceiling will require the

reinforcement to accommodate movement between the panels. The joining of the panels would likely result in additional cracking outside the area of reinforcement.

This issue of not sealing the joints for fear of contributing more cracks to the existing pattern was an important issue to consider when it came time to treat the plaster. The fact that each panel was responding independently to the flexing of the ceiling suggested that binding existing panels together would not solve the flexing issues and as such would result in the development of new cracks.

FORD FAREWELL MILLS AND GATSCH ARCHITECTS
ARCHITECTURAL, ENGINEERING, AND CONSERVATION OF DRAYTON HALL, CHARLESTON, SOUTH CAROLINA
JULY 1998

This extensive report is the first to begin to address the interrelationship of existing problems throughout the house based on three areas of concern outlined in the Request For Proposal which included:

- Moisture related damage to exterior masonry and mortar and interior plaster and wood elements
- Discoloration, fading, and disintegration of interior paint finishes
- Cracking, ornamentation loss, and delamination of the plaster ceiling from the Great Hall

The National Trust felt that it was imperative that the project relating to this document include a range of specialists who could interact with each other to gain a better understanding of individual problems by looking at the more significant issues of causation.

Regarding the Great Hall ceiling, one of the most important issues outlined was not a method for correction as much as an awareness of a chronic problem. The authors state, “While it appears that the work that was done improved the condition of the building, it did not totally resolve the conditions causing the damage. The fact that so many experienced professionals have investigated this problem without concurring on an answer is a good indication that no simple solution exists.” What this report does not address is that poor documentation and lack of communication have been a major contributing factor to just that issue.

Additionally, the problem may ultimately be unresolvable requiring a new approach which recognizes the need to mitigate rather than completely "fix" the problem every twenty years.

The report outlines hypotheses regarding the ceiling stating,

> Prior to the 1970's ceiling modifications, consultants retained by the Trust believed that the majority of cracking was caused by flexure of the floor joists which are undersized for the span. The current study (for which this report is the end product) has been expanded to also consider the possible effects of thermal and vibration resources. The 1970's structural and consolidation work, while stiffening the floor joists, may have made the entire monolithic construction more susceptible to vibration damage to the finish plaster material.

The repair work carried out in 1978 is addressed due to a concern of the thermal differential between the original materials and those installed for the treatment. The report concludes "That effects of thermal expansion can be shown to be negligible.

Several different schemes for strengthening the second floor to allow for visitor traffic are outlined in this report however the stressed skin approach was selected just prior to plaster treatment in 2002.

George Fore's suggestions for treatment of the failing plaster refer back to the 1991 University of Pennsylvania Conditions Assessment, which had identified three areas of concern. These areas included an area directly over the second floor hearthstone, an area between the center medallion and the north wall, as well as a portion between the center medallion and the west wall. Fore states "The conservation treatments of the Great Hall ceiling should include these three panels as a minimal scope of work. All other areas of un-keyed plaster identified in the 1991 study are located at the edges of plaster panels and do not appear to affect the integrity of the plaster." Fore's plan involved the introduction of adhesive anchors which would be inserted into holes drilled from above. According to Fore, "The most difficult task in the introduction of new anchors to the plaster is judging the depth of the historic plaster. As shown on the drawing, a small pilot hole is drilled from the underside of the plaster to aid as a depth gauge."

While this hole would be smaller than the actual hole drilled for the anchor. It would still require the introduction of a hole drilled through the visible surface. The suggested treatment using anchors was seen as problematic since the area held in place by the anchors would only be limited to that area in contact with the anchor. Knowing that the existing scratch coat was already extremely weak and friable would only reduce this area of attachment, since "tear-out" would be limited to a smaller area.

Fore was careful to point out that this "anchoring technique should only be employed at loose panels which demonstrate a progressive loss of bond to the plaster substrate." This point suggests for the first time that the treatment of the ceiling should not be carried out uniformly as it was in 1978 instead focusing only on the areas where emergency treatment was imperative.

APPENDIX B

LITERATURE REVIEW

	AUTHOR	No testing	No Treatment	Crack Filling	Reattchment	Consolidation	Type of consolidant/adhesive	Brand Name	Medium	mechanical properties	Instrumental Analysis	STANDARDS
				TREATMENT						MATERIALS TESTING		
1	Franco, Maria Luisa	√		√	√		Polyvinyl Alcohol Adhesive, (A) Polyvinyl Acetate Emulsion, (A)	Endurol Mowilith DM4	Distilled Water	Cross section analysis		
2	Espinosa, Agustin	√			√		polyvinyl acetate, (A) Calcium Caseinate, (A)					
3	Cobau, Andreina Costanzi				√	√	paraloid B-72,(C) Iccrom Formula (Article 17),(A)					
4	Brown, Gordon E									Mortar digestion Compressive Strength and Hardness	XRD, SEM, Unit Weight Absorption Lime Content Microscopic examination	ASTM C457 ASTM C128 CSAA179-M1976
5	Zanachko-Iavorskii, Igor		√								Microscopy	
6	Henrigues, F.M.A.		√							***Extensive-Please refer to article Table-1***		***Extensive-Please refer to article Table-1***
7	Atzeni, C. L Massidda		√								XRD MIP SEM EDS	ASTM C230 (workability) EN 196/1 (mixing sample) EN 196/1 (compressive strength)
8	Giuffrida, R., M.		√							Mortar Digestion Sieve separation		DIN 4188 part 2(Sieveing)
9	Halstrom, Ingmar.		√							Compressive strength,Tensile strength, Modulus of Elasticity, Adhesion, Pore Structure, Water Absorption		***No Standards Given***

10	Tubb, K				√	√	cellulose nitrate, (A) paraloid B-72,(C) poly vinyl alcohol, (A)	Primal WS24	toluene	Mortar Digestion,	XRD, SEM, EDS	***No Standards Given***
11	Giovanninni, P.	√	√									***No Standards Given***
12	Peroni, S. Et Al		√							Carbonation, Flexural strength, Setting time, wet compaction into moulds,Moulding, Mixing, Water absorption and porosity, Weather resistance,Adhesion, Workability, Setting time	Absorption spectrometry	DM 1968, DM 1968 same as ISO, ASTM C 191-77,ASTM C109 or C348BRE IS 14, 1978(ASTM C780-74, cone penetrometer, BS 4551, 1970, flow table and dropping ball, ASTM 149-66UNESCO/RILEM 1978 and NORMAL F 27/80 .
13	Sickels, Lauren-Brook.		√							strength,reliability, comparative analysis,biological attack		***No Standards Given***
14	Jacob, Judith		√									ASTM E 96-80, ASTM C 270-87a ASTM C 144-84
15	Down, Jane L,		√				vinyl Acetate (A) Acrylic Adhesives (A)			refer to bib		ASTM D 412, ASTM D 1583-61,ASTM D 2370-82
16	Ferragni, D., M. Forti			√	√		poly vinyl alcohol, (A)	Primal AC33	Distilled Water	Time,Marsh Cone and Perspex Tube for Viscosity and	Mercury Porosim	'Vapor Permeability' test II.5
17	Mora, Paolo and Laura Mora	√	√									***No Standards Given***
18	Bradley, Susan.		√							Three point testing, Modulus of Elasticity, Shear, Peel, Tensile Strength, Compressive Strength		ASTM D1876-611,ASTM D903-49,ASTM D897-49,ASTM D1344-57,ASTM D1002-64
19	Matero, Frank G.	Please refer to article23		√	√	√	Acrylic Emulsion (A)	El Ray Superior 200,Riverton Lime				***No Standards Given***

20	Aslam, M.		√								SEM,XRD,IR Spectra,Thin Section,Gravimetric Analysis	***No Standards Given***
21	Matero, Frank G. and Angelyn Bass.		√					Rhoplex E-330	Distilled Water	Setting time,Shrinkage,Injectability,compressive loading,water vapor transmission	SEM,XRD	ASTM D905-89, ASTM E96-80 ,ASTM C496-90 ,ASTM C474-67 ,ASTM C191-77 ,ASTM C939-87
22	Barger, M. Susan									pH, Munsell Color matching, Ignition used to ID weight of organic matter,	Dispersive X-ray Spectroscopy, XRD	***No Standards Given***
23	Phillips, Morgan W.		√						Distilled Water,ammonia	Flexibility, hardness, water resistance,absorption through model plaster test (Similar to water absorption test)		***No Standards Given***
24	Verrall, W.		√							Tumbler test (to Identify colloids, most notably ferric Hydroxide, in sand),Heating of sand to identify Ferric Hydroxide,Nitric Acid and Silver Nitrate to identify Sodium Chloride.		***No Standards Given***
25	Phillips, M.W.		√					Rhoplex MC-76 Rhoplex LC-67Acrysol ASE-60	Distilled Water	A creep test to determine the nature of the adhesive is suggested yet no specific test is identified.		***No Standards Given***
26	Newton, R.G.											
27	Bergman, Richard							Rhoplex MC-76 Rhoplex LC-67Acrysol ASE-60	Distilled Water			
28	Koob, Stephen P.	√			√			Paraloid B-72	Acetone			***No Standards Given***
29	Mora, Paolo and Laura Mora	√	√				Calcium Caseinate		Distilled Water			***No Standards Given***
30	Torraca Georgio.	√	√				Thermoplastic resins, Thermosetting Resins					***No Standards Given***

Figure 1A: Drayton Hall (west land elevation ca.1900)

Figure 1B: Drayton Hall (west land elevation 2002)


Figure 2A: Great Hall, view looking southwest. (photographer: J.Schwartz, 1978)

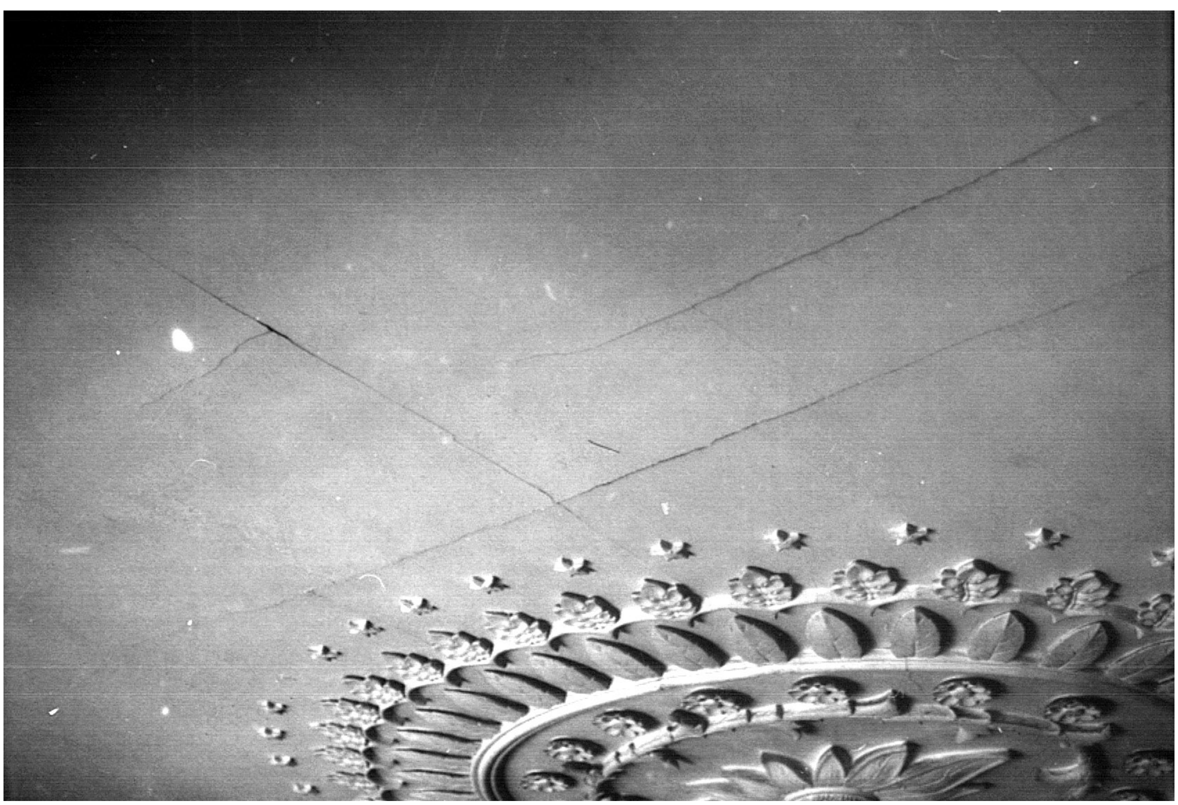
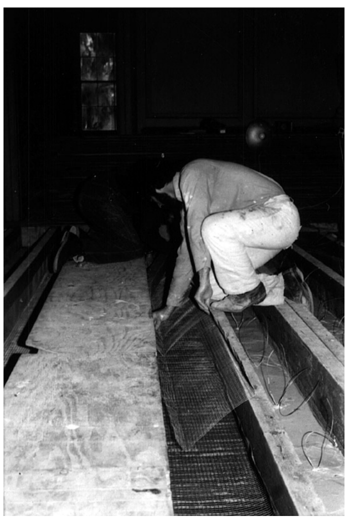


Figure 2B: Great Hall detail before stabilization. (photographer: J.M. Garrison, January 15, 1978)

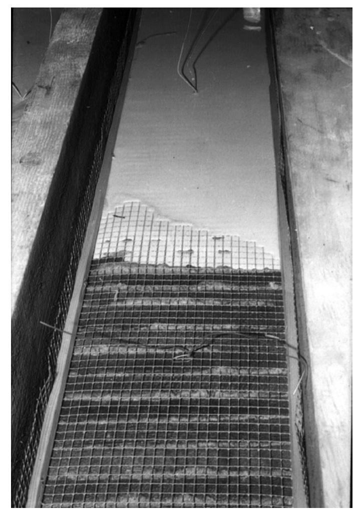

A. Temporary stabilization.

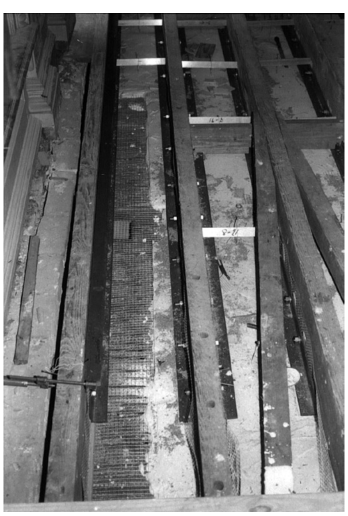

B. Debris removal.


C. Cleaned and pre-wetted lath.


D. Wire mesh installation.


E. Plaster pour.


F. Plaster mesh assembly.


G. Steel angle attachment.


H. Steel angle attachment.


I. Total system in place.

Figure 3: 1978 ceiling stabilization sequence. (photographer: J. M. Garrison)

Figure 4: Great Hall, view looking southeast. (photographer: Frances Benjamin Johnston ca.1938)

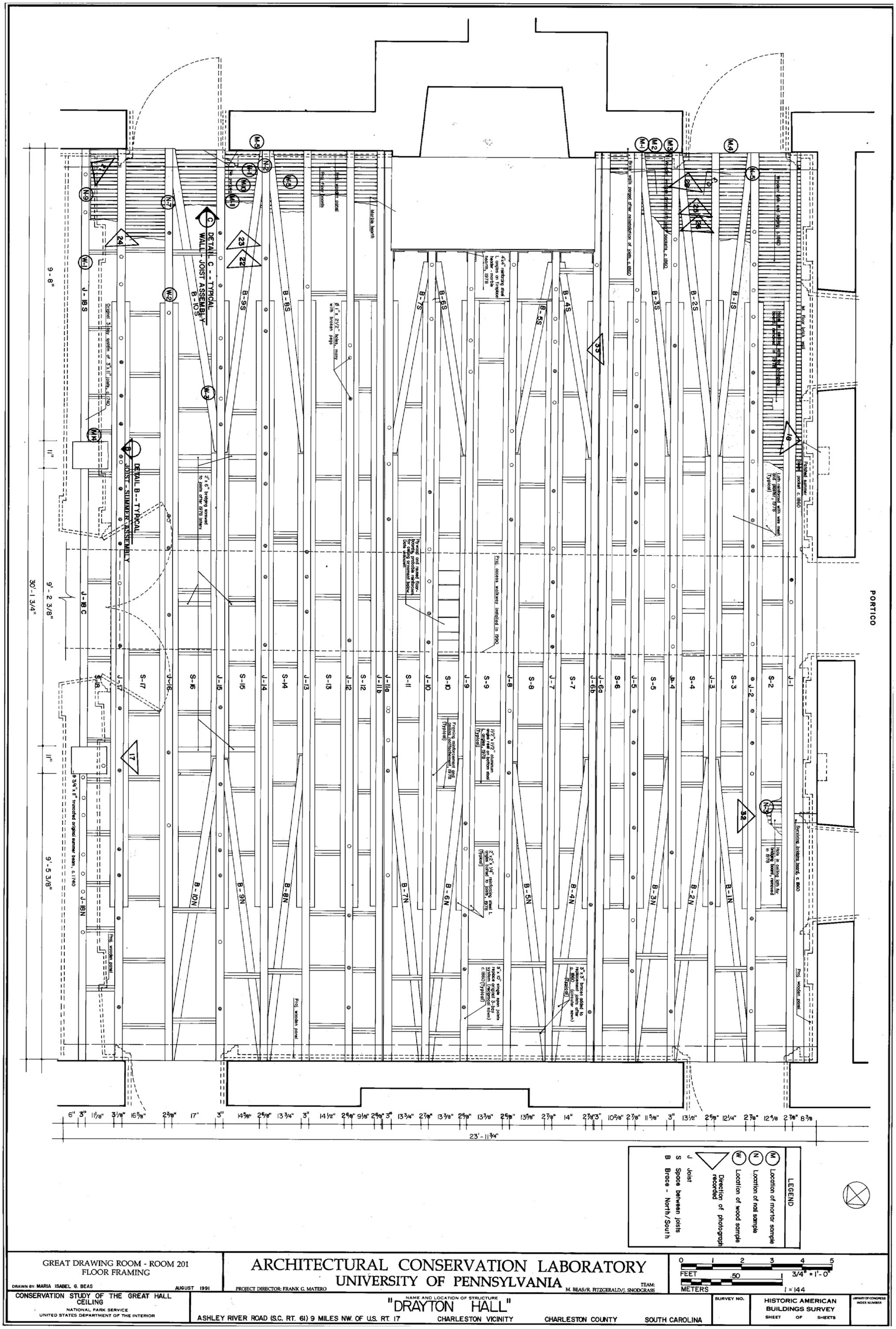


Figure 5:1991 framing plan.

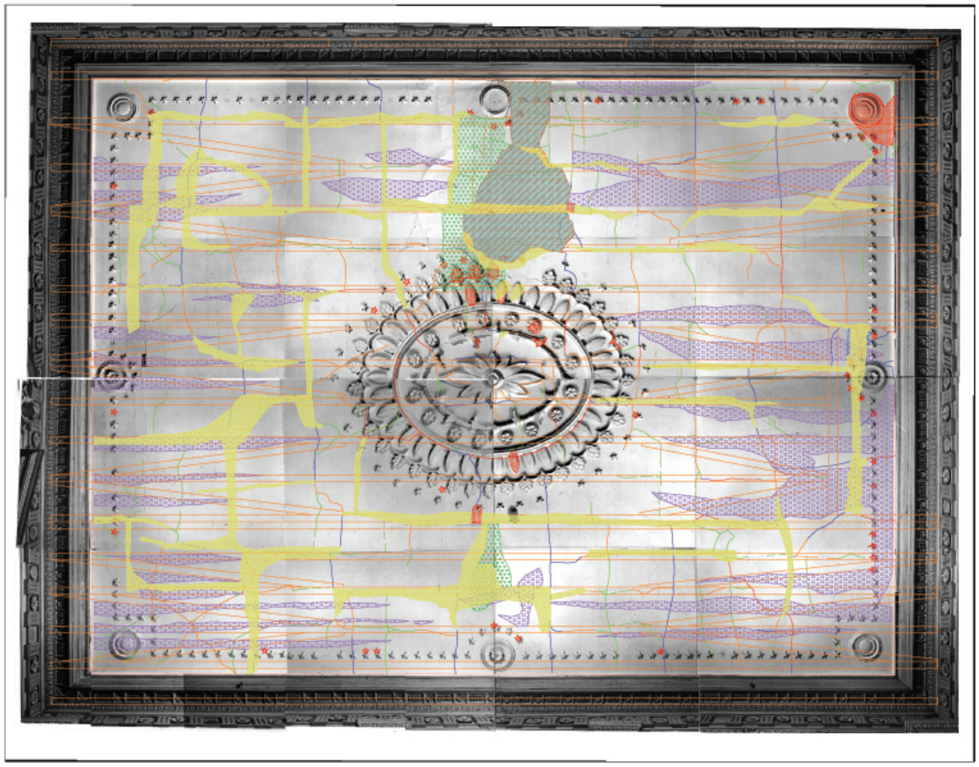


Figure 6: 1991 ceiling conditions with framing plan.

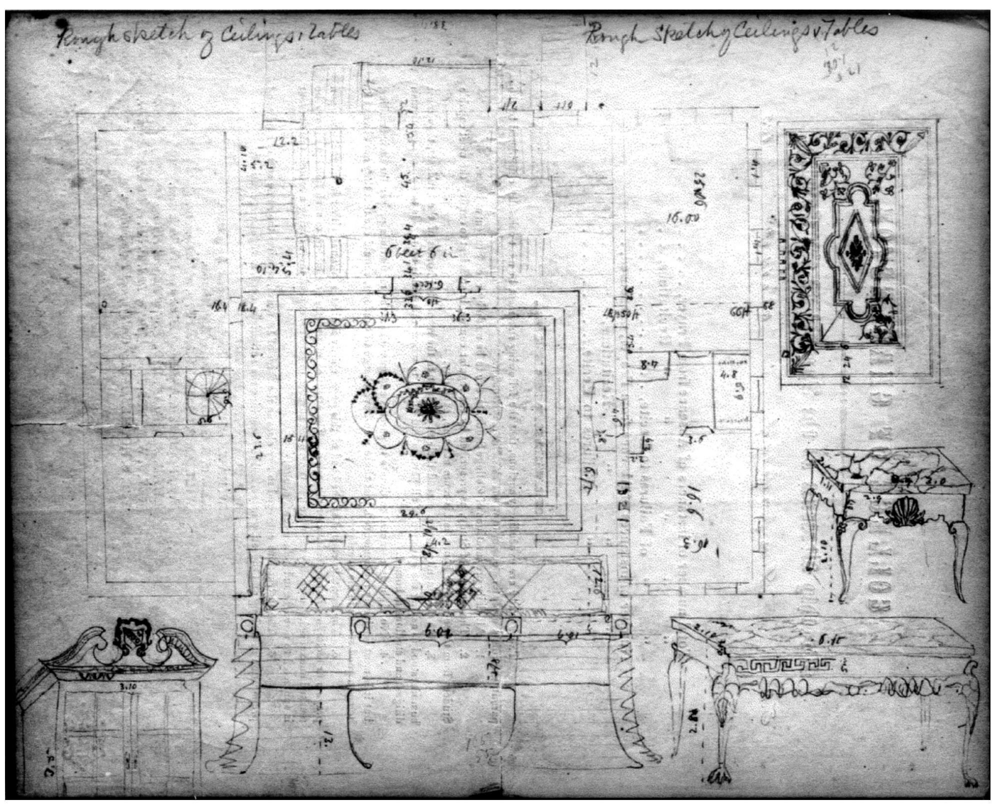


Figure 7: Great Hall ceiling (center design) from Louis Reeve Gibbes sketchbook, ca.1845.

Figure 8: Detail of recent plaster loss. Note only partial reattachment from 1978 treatment.

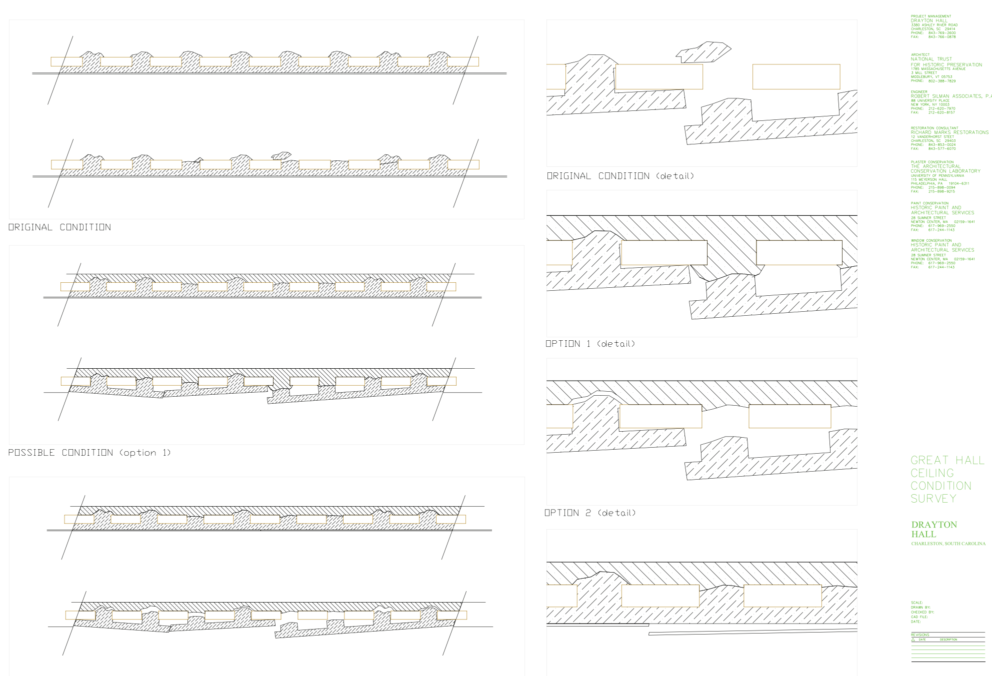


Figure 9: Schematic section of various plaster ceiling conditions before and after 1978 treatment.

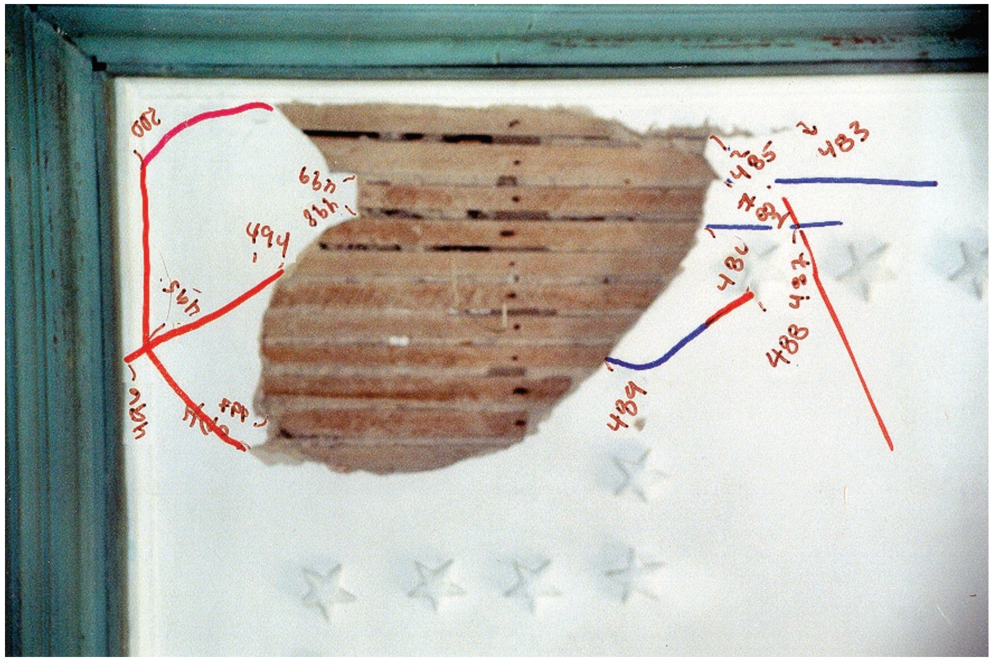


Figure 10: Impact damage from Hurricane Hugo preparation, 1989.

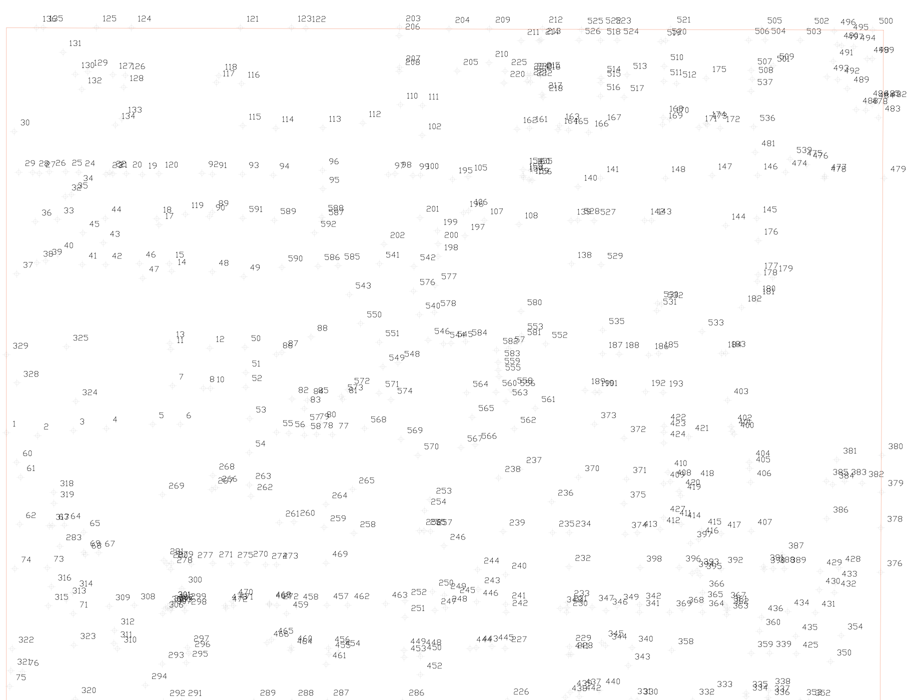


Figure 11: AutoCAD Map of crack intersections.

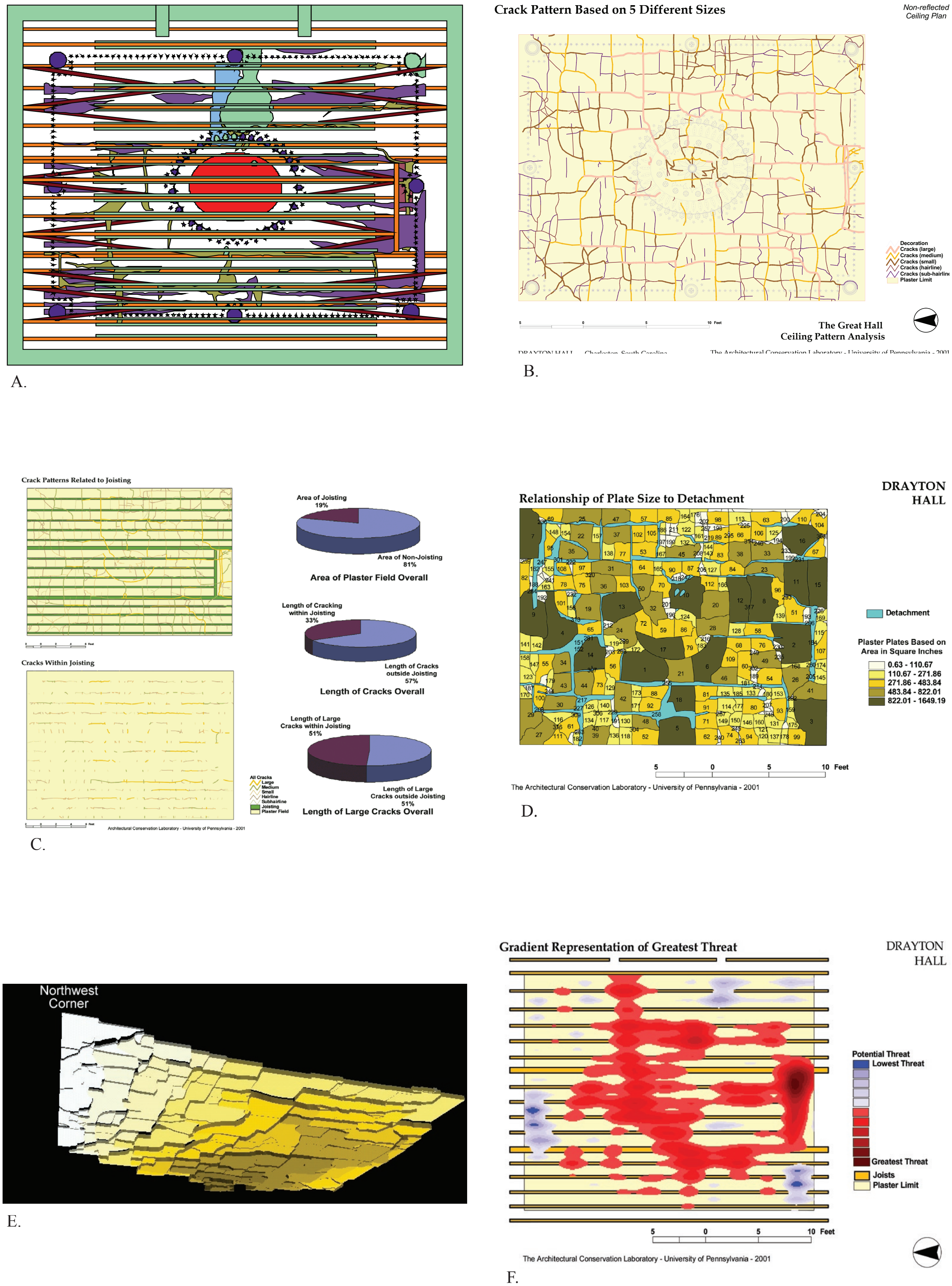


Figure 12: GIS assessment sequence of the ceiling.

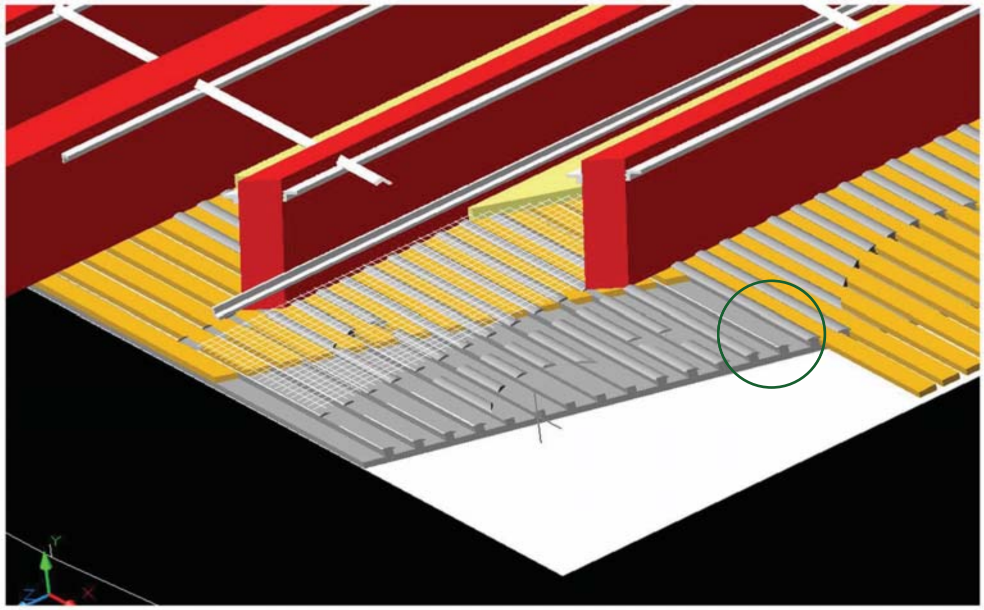


Figure 13A: Schematic isometric view of existing floor-ceiling system (view from above)

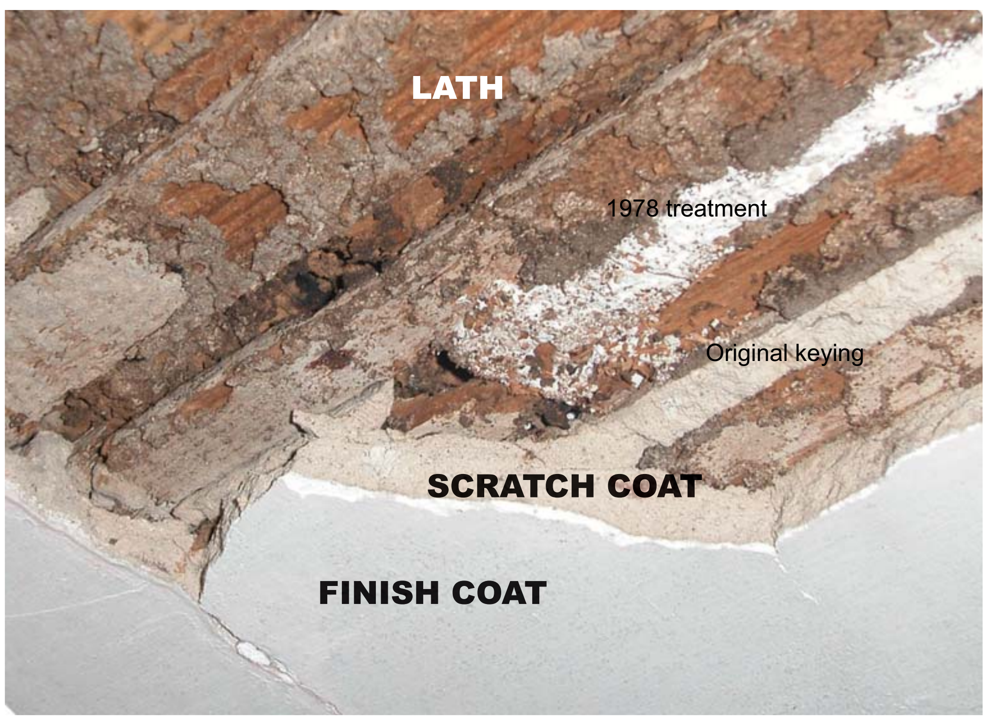


Figure 13B: Detail of original plaster-lath system (view from below)

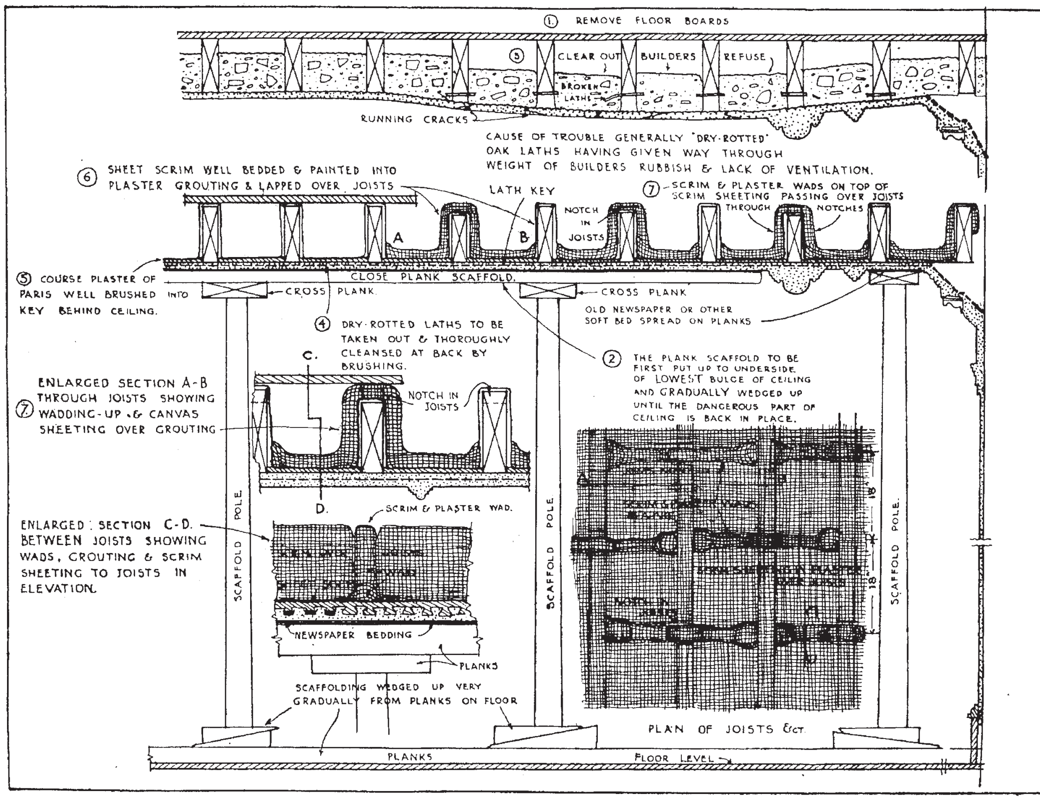


Figure 14: Method of strapping and reinforcing defective old plaster ceilings. (Millar, 1897)

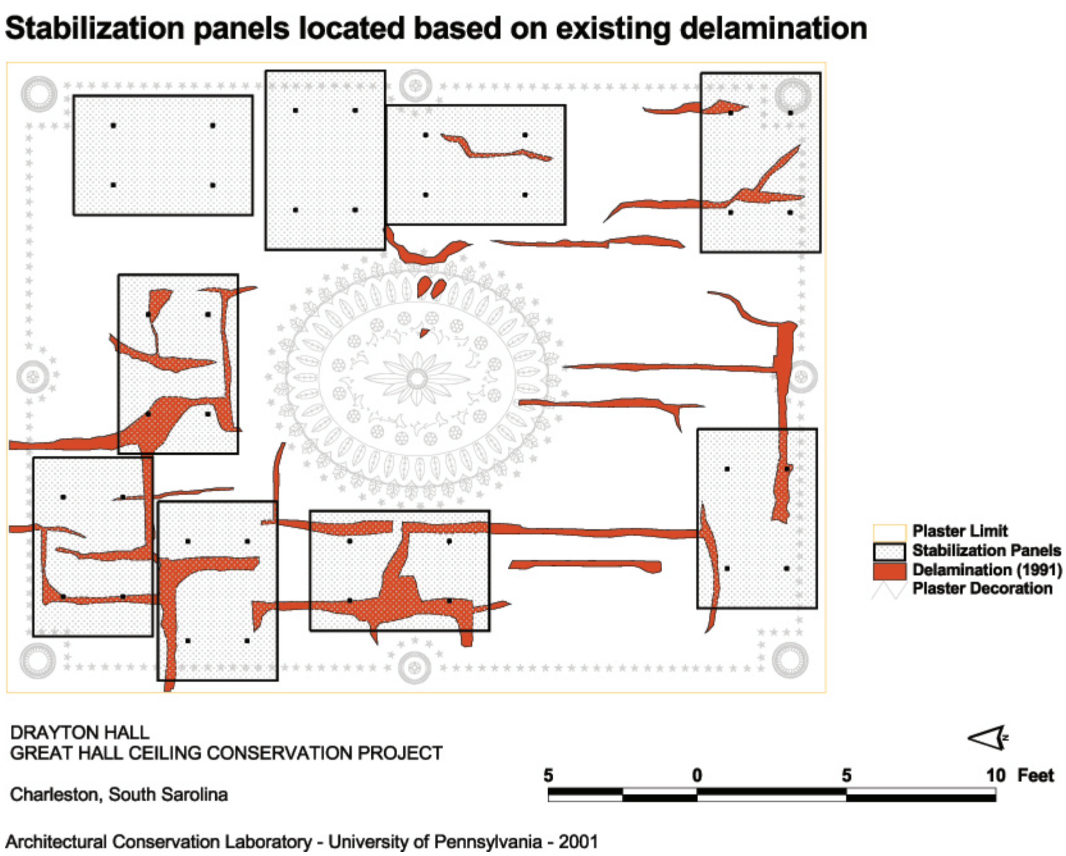
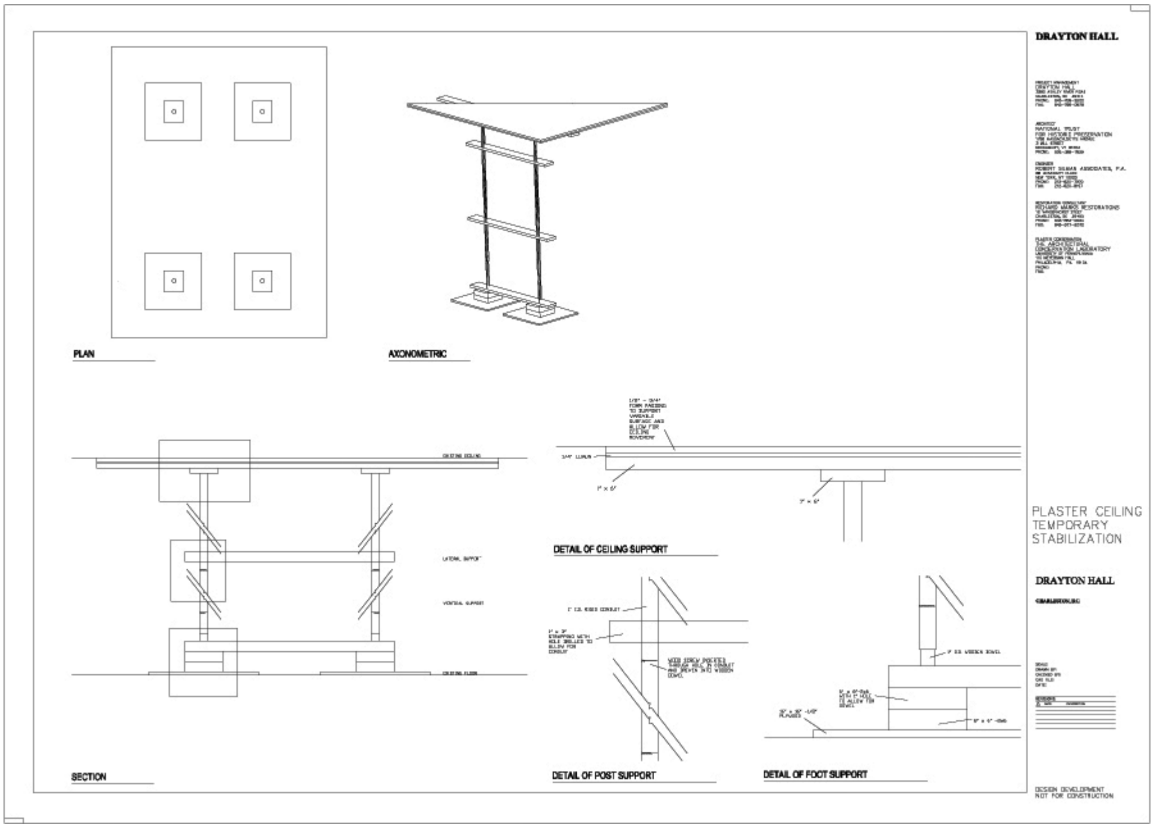
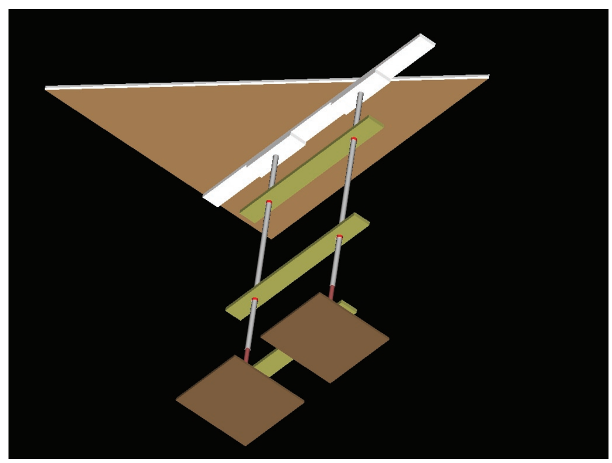


Figure 15: Identified areas for temporary stabilization, 2002.





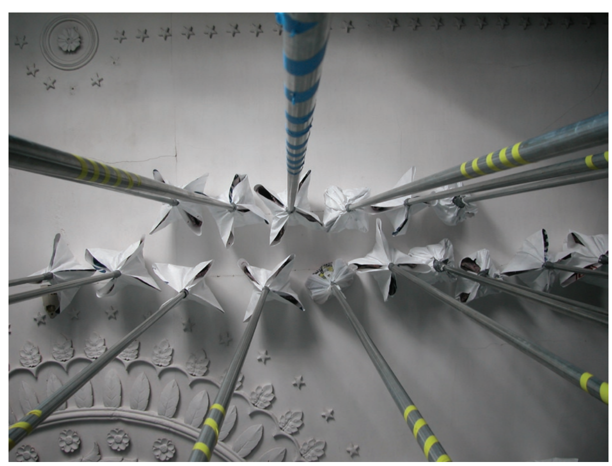


Figure 16: Temporary stabilization support

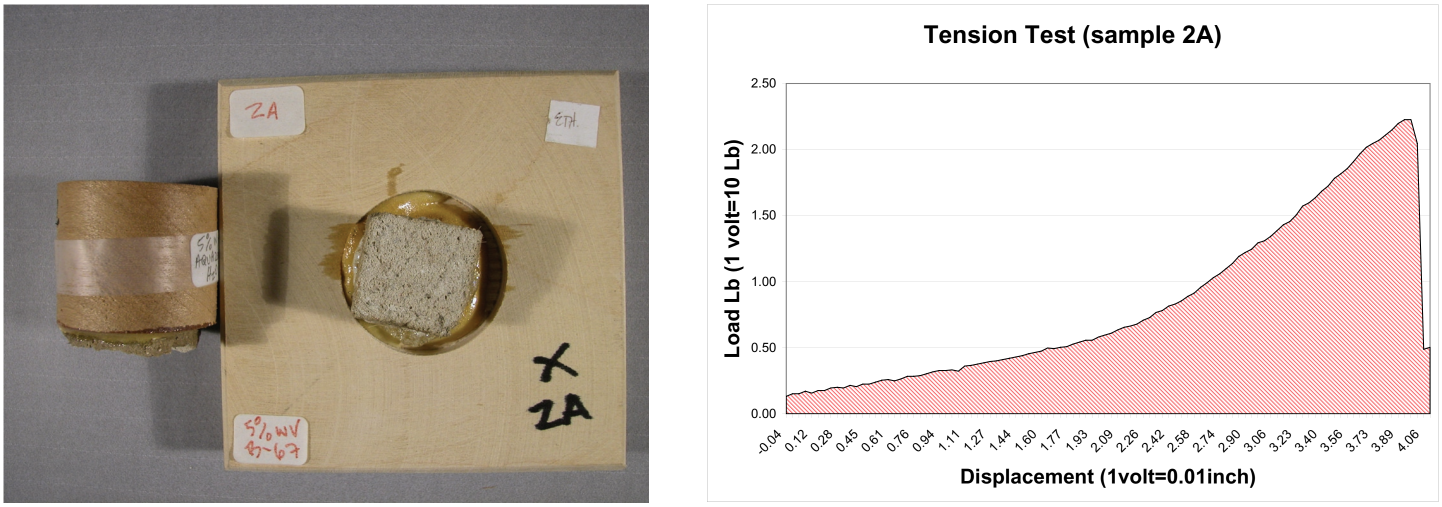


Figure 17A: Sample 2A- Scratch coat to scratch coat with filled adhesive.

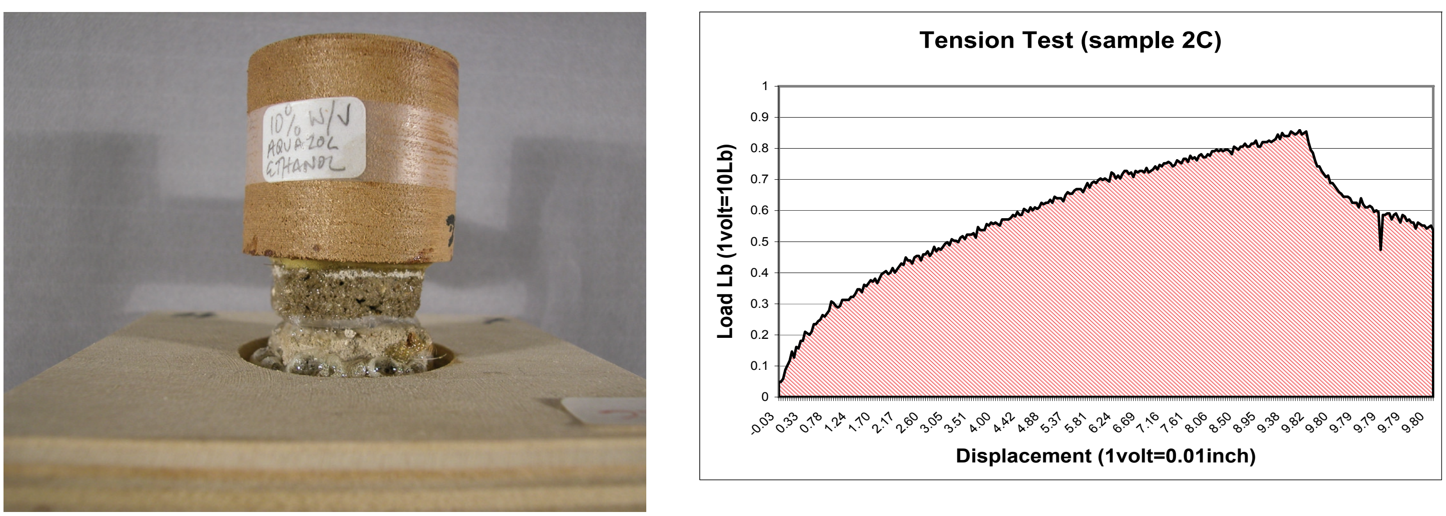


Figure 17B: Sample 2C- Scratch coat to scratch coat with unfilled adhesive.

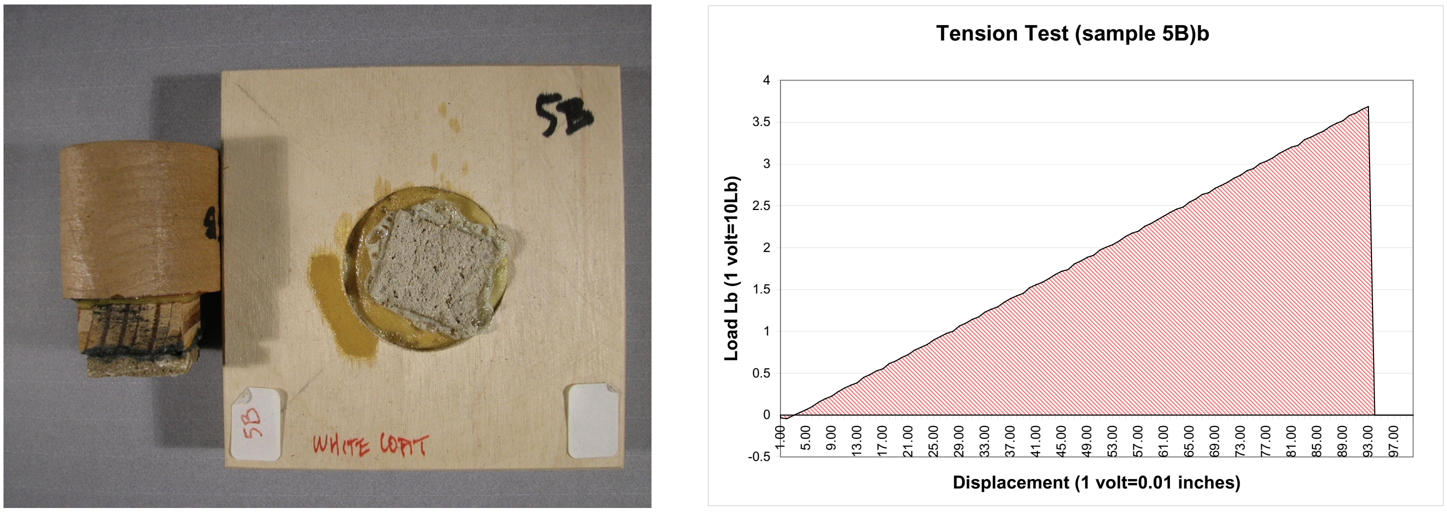


Figure 18A: Sample 5B- Scratch coat to wood with filled adhesive.

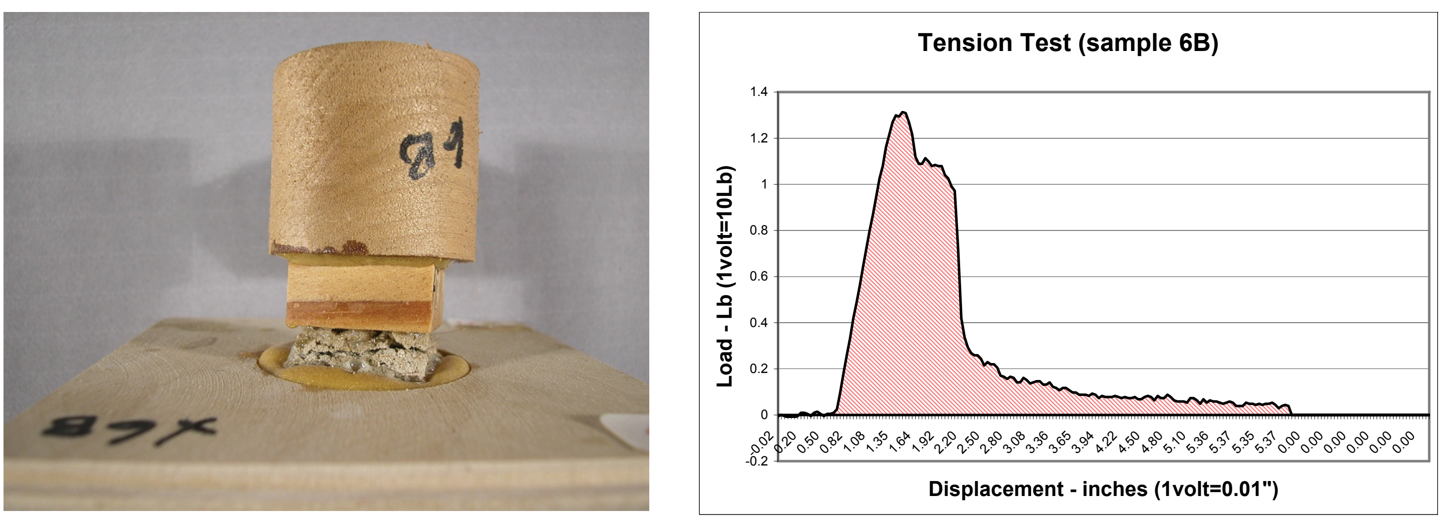
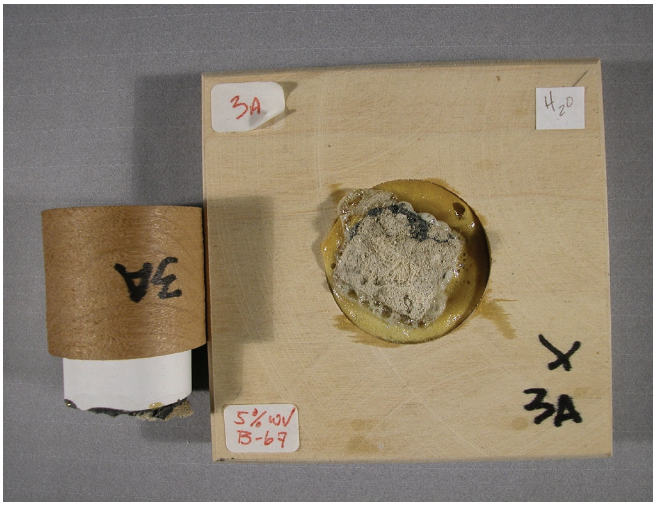


Figure 18B: Sample 6B- Scratch coat to wood with unfilled adhesive.



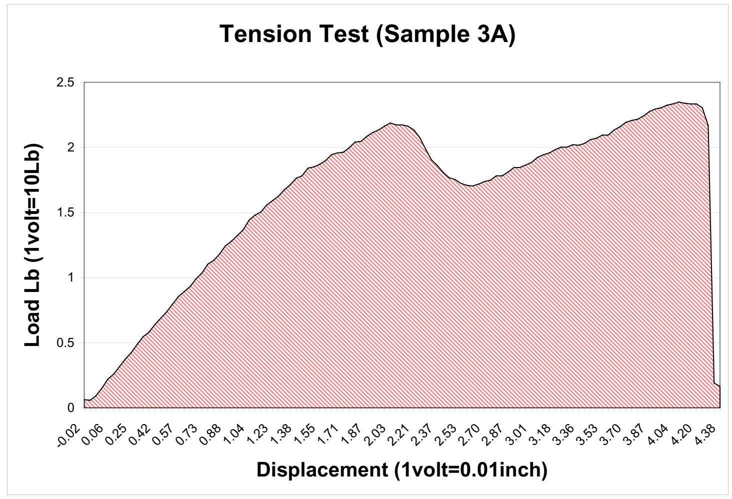
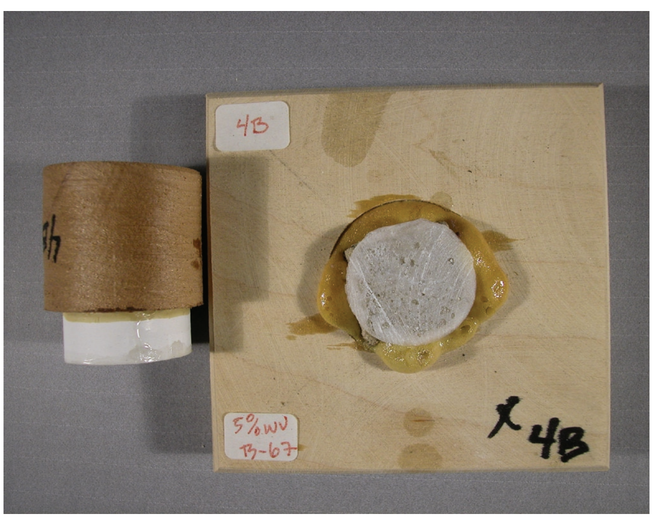


Figure 19A: Sample 3A- Scratch coat to finish coat with filled adhesive.



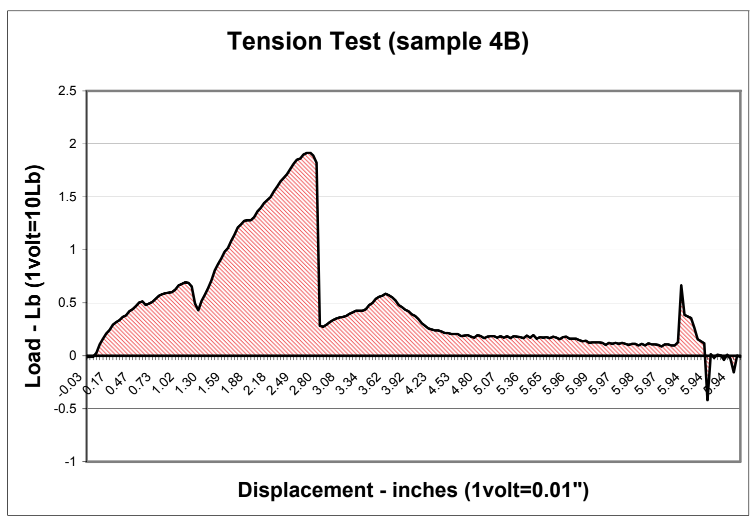
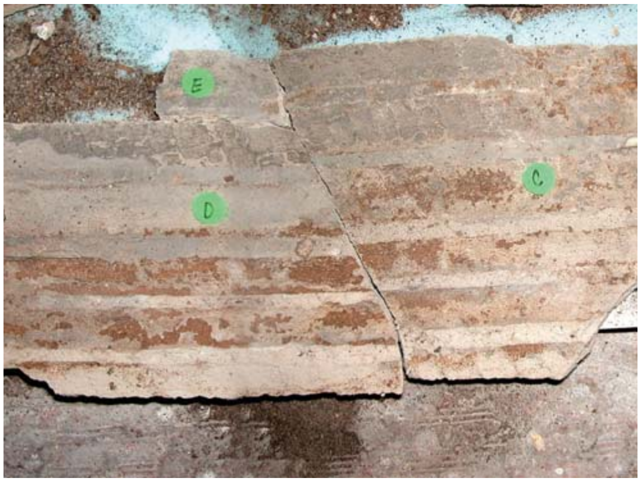


Figure 19B: Sample 4B- Scratch coat to finish coat with unfilled adhesive.

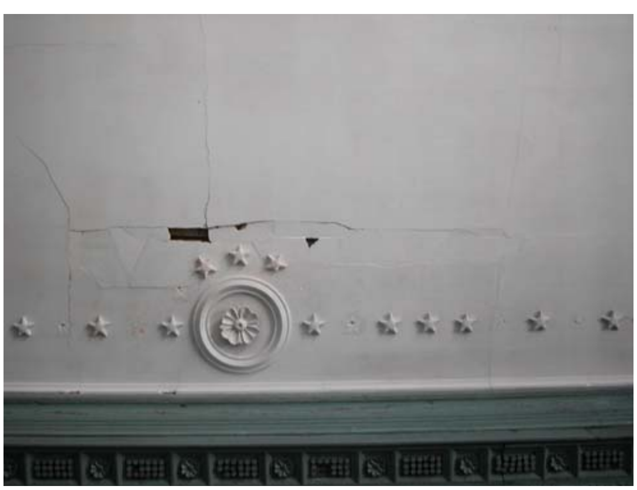


A. Removed and reassembled fragment


B. Preconsolidation


C. Application of adhesive


D. Temporary support


E. After treatment, before fill

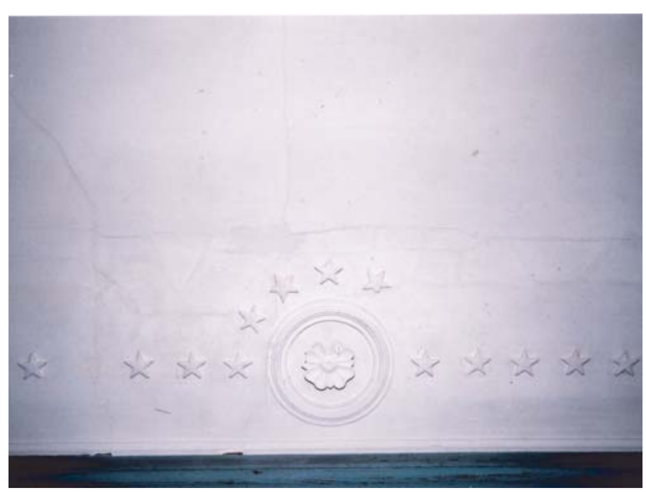

F. Ceiling after completed treatments.

Figure 20: Complete reattachment sequence

Figure 21A: Southeast corner before repair.

Figure 21B: Southeast corner after repair.


A. Overview of ceiling reattachment.


B. Drilling injection holes for grouting.


C. Debris removal with compressed air.


D. Preconsolidation of scratch coat.


E. Injection grouting.


F. Overflow removal.


G. Cleaning of the ceiling surface.


H. After grouting and filling.


I. Ornament reattchment.

Figure 22: Pre-consolidation and injection grouting.

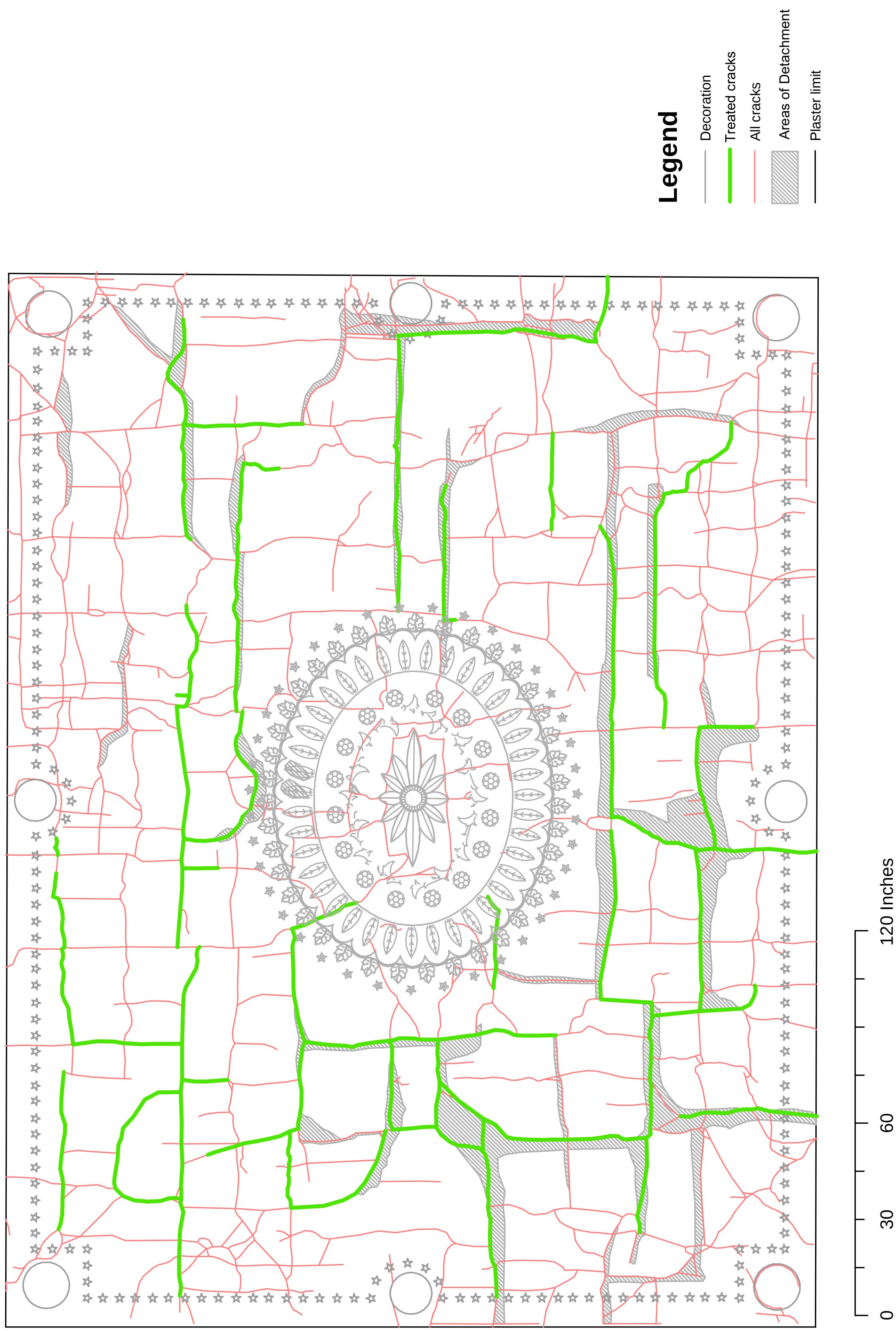


Fig. 23 Mapping of treated cracks, 2002.