OKLAHOMA STATE CAPITOL
Exterior Facade Investigation

2300 North Lincoln Boulevard
Oklahoma City, Oklahoma 73105

Final Report
December 18, 2014
WJE No. 2014.3319

Prepared for:
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WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

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EXECUTIVE SUMMARY

At the request of Mass Architects, Inc. (MAI), Wiss, Janney, Elstner Associates, Inc. (WJE) performed an investigation of the exterior walls at the Oklahoma State Capitol (Capitol) in Oklahoma City, Oklahoma. MAI is serving as technical representative to the Office of Management and Enterprise Services (OMES); OMES will be in charge of overseeing planned exterior repairs and interior renovations to the Capitol. This report summarizes findings from our investigation and presents our recommendations for implementing long-term repairs for the exterior walls of the Capitol.

Our investigative procedures sought to capture the necessary information to develop a scope of work for the restoration of the exterior walls of the building, including:

- Limestone, granite, and other masonry cladding
- Windows and exterior doors
- Related decorative exterior metalwork

Our approach included the following tasks:

- Review of existing documents including original drawings, specifications, and previous reports on the condition of the facade
- Preparation of survey sheets from original drawings to document existing conditions
- Non-intrusive (visual) survey of the building from grade, roof levels, and close-up via industrial rope access (difficult access techniques or DAT)
- Examination of concealed conditions at intrusive inspection openings made at both distressed and non-distressed areas of the facade
- On-site studies using field microscopy to understand the extent, pattern, and nature of discoloration, staining, and deterioration
- Cleaning trials were performed on limestone facade areas and destructive and non-destructive techniques were used to study door and window materials and coatings
- Laboratory studies of limestone and mortar to assess existing conditions and assist us with developing long-term repairs

In general, considering the age of the Capitol, the exterior walls are in fair condition, and, upon the completion of repairs and future on-going maintenance, we would expect many decades of continued service for the State of Oklahoma.

The distress conditions observed at the Capitol are typical for a building of this construction type and vintage. The most prevalent distress condition is the deterioration of existing mortar, including bond separation, cracking, and wash-out, that exists throughout both granite and limestone facade areas of the building. Corrosion of embedded mild steel anchors has caused cracking and spalls in the limestone cladding. Other cracks, particularly at the outside corners of the building, are likely the result of the unaccommodated and differential movement between the limestone cladding, brick masonry backup, and concrete building frame.

Corrosion of the steel-framed windows and cast iron elements on the main facades is related to deterioration of exterior coatings and moisture migration through the exterior walls and subsequent corrosion of concealed portions of the steel frame. Another contributing factor of the corrosion of the steel window frames is the lack of a thermal break between the interior and exterior metal surfaces, a condition that produces condensation on the frames.

In 2011, the State of Oklahoma installed barricades and scaffolding near the south entrance of the building to reduce the likelihood of pedestrians being struck by falling debris. During our investigation, WJE removed a few imminent limestone spalls that posed a risk to pedestrians on the north and south facades. There are a few conditions, such as exfoliation of limestone on the south facade frieze (portico), where existing distress necessitates maintaining the barriers and sidewalk canopies that are presently in place to protect the public from potential falling hazards. The barriers and canopies should remain in place until such time that long-term repairs can be performed.

The recommended repairs generally consist of the following:

- Install dutchman repairs and/or replace cracked or spalled limestone.
- Replace limestone with significant exfoliation; panels with surficial exfoliation may remain in service.
- Remove and reinstall or replace select limestone units concurrent with removal and replacement of original embedded mild steel anchors. Original mild steel anchors should be replaced with stainless steel anchors.
- Repoint all original exterior masonry facades (granite and limestone).
- Grind along the length of limestone and granite cracks, and install backer rod and sealant.
- Remove biological growth on the limestone and granite facades.
- Perform selective repairs to cracked and spalled limestone and brick masonry parapet facades. The repairs should address corrosion of mild steel anchorages for the limestone parapet and cornice, lateral support of the limestone parapet, water intrusion, and permeability of the brick masonry.
- Replace original steel-framed windows. Cast iron spandrels and perimeter ornament should be stripped and recoated.
- Remove and rebuild the concrete light well walls.
- Investigate the cause of the cast stone cracking at the base level of the dome. Recommended repairs, if any, should be implemented based on further investigative studies.

The recommended treatments are more fully described at the end of this report and are consistent with the *Secretary of Interior's Standards for the Treatment of Historic Properties*. The recommended repairs are designed to retain and repair the building's historic fabric with particular sensitivity for all character-defining features on the primary and secondary public facades.

Replacement of historic materials is recommended for specific areas of the facade due to significant levels of deterioration that necessitate such action. When possible, material will be replaced with like material. In the case of the windows, sight lines will be maintained. Recommended cleaning techniques are based on using the gentlest means based on field trials performed during the investigation.

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INTRODUCTION

In 2010, MAI prepared a *State Capitol Building Historic Conditions Report* (2010 report) that included an evaluation of the building structure, exterior walls, interior finishes and building systems. For the long-term sustainability of the Capitol, the 2010 report recommended that the exterior facade be restored as a primary goal to mitigate continued deterioration. As a first step to implementing long-term facade repairs, the 2010 report recommended an investigation to further examine the condition of the exterior walls including a study of previous facade treatments and identify the cause(s) of observed distress.

The State of Oklahoma recently passed legislation that authorizes the sale of bonds to pay for renovations described in the 2010 report. It is our understanding that the schedule for exterior wall repairs is likely to be accelerated compared to the schedule for interior renovation.

This report summarizes findings from our investigation and presents our recommendations for implementing long-term repairs for the exterior walls of the Capitol.

BACKGROUND

The Capitol was designed by the architectural firm of Layton and Smith, and construction began with a ground-breaking ceremony on July 20, 1914. The building was completed in 1919. A dome was included in the original conceptual designs but not constructed until 2001.

Building Description

The building is predominantly cruciform in plan with wings that project east, west, north, and south from the center of the building. The overall plan dimensions are approximately 434 feet in the east-west direction and approximately 304 feet in the north-south direction. The north and south wings each have gabled roofs and pediments, and an entrance portico exists at the south wing of the building. The east and west wings have a combination of gabled roofs, pediments, and flat roof areas. The east and west wings house the legislative chambers. The five-story original structure is a reinforced concrete building frame and the exterior walls are clad with Indiana limestone and multi-wythe brick masonry backup. The main roof level is approximately 75 feet above grade, and the top of the dome is approximately 210 feet above grade. Windows have painted steel frames, cast iron moldings, and ornamental cast iron spandrels. Representative plans and elevations reproduced from the original drawings are shown in Figure 1 through Figure 4.

The dome structure is a combination of concrete and steel framing and clad with cast stone. It was designed and constructed under a design-build contract and completed in 2002. Representative details reproduced from the 2002 drawings are shown in Figure 5 and Figure 6.

A diagram of the building illustrating terms used throughout this report can be found in Figure 7.

METHODOLOGY

Our evaluation of the Capitol exterior walls consisted of three fundamental tasks: document review; on-site investigation; and on-site and laboratory studies. More specifically, our investigation included the following tasks:

- ***Task 1: Document Review***. We reviewed original drawings, specifications, and engineering reports provided to us to become familiar with the specified design of the exterior walls and various locations where previous repairs have been performed on the building.

- ***Task 2: Survey Sheets***. From baseline computer-aided drawing (CAD) drawings provided to us by MAI, we prepared survey sheets of each facade to document conditions within an electronic database using tablet technology. The tablet technology allowed us to identify the exact location where distress is observed, examine patterns of distress, and ultimately recommend the facade areas where repairs should be performed.

- ***Task 3: Non-Intrusive Inspections***. We performed non-intrusive visual inspections on all accessible areas of the building facade including the drum base and dome using industrial rope access techniques. Our close-up inspections were supplemented with additional inspections from grade, various roof levels, and the backside of exterior wall areas at accessible attics. Observed distress conditions (cracks, spalls, exfoliation, staining, and displacement) were documented on our survey sheets. Metal detectors were used at representative exterior wall areas to assist us with identifying locations and spacing of embedded mild steel anchors.

- ***Task 4: Intrusive Inspections***. To better understand key exterior wall details and how various cladding elements were originally designed and constructed, intrusive exterior and interior inspection openings were created and examined at both distressed and non-distressed facade areas. The inspection openings were made and repaired by qualified contractors. Existing conditions were documented with sketches and photographs. Temporary repairs (with in-kind materials) were performed by the contractor to maintain the weathertightness of the existing construction.

- ***Task 5: On-Site Studies***: To understand the extent, pattern, and nature of discoloration, staining, and deterioration, petrographic and conservation evaluation was performed at representative locations using field microscopy. We performed cleaning trials with a combination of systems for the exterior masonry facades. We used a combination of destructive and non-destructive techniques to evaluate window and door components.

- ***Task 6: Laboratory Studies***. We performed laboratory analysis of various materials to identify likely causes of observed distress and to insure that appropriate repairs are recommended that will not damage, alter the appearance, or reduce the potential of performing future work on the exterior walls of the building.

MAI and OMES Division of Capital and Asset Management (DCAM) assisted us with our on-site investigation, providing access and contractor assistance for creating and repairing intrusive inspection openings.

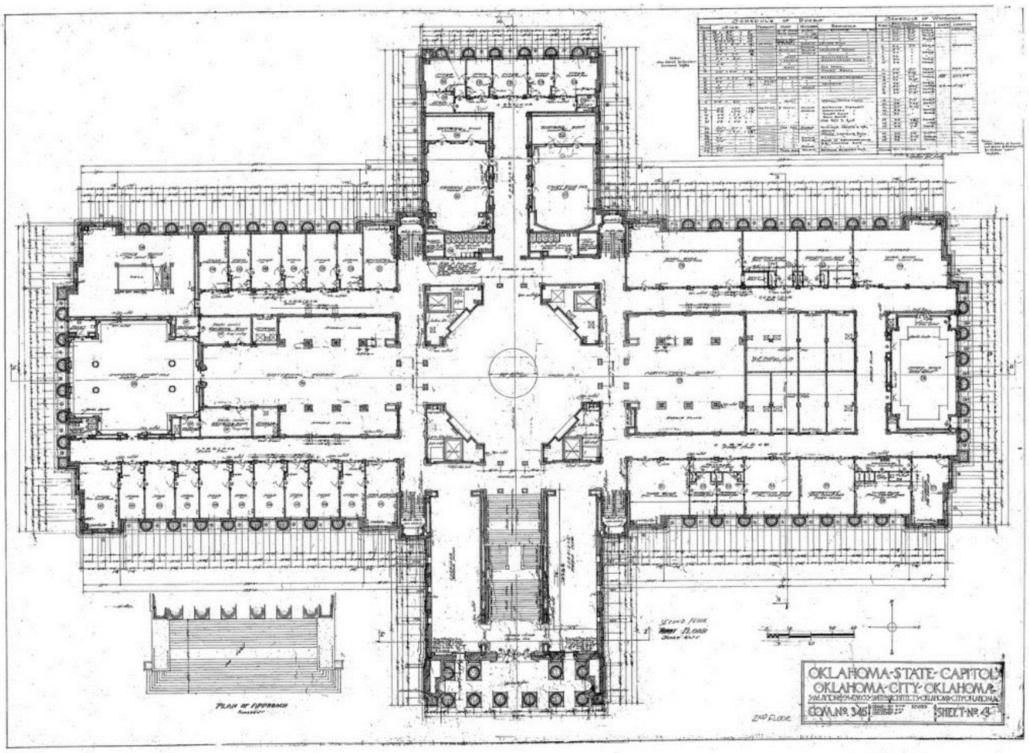


Figure 1. First floor plan reproduced from original drawings

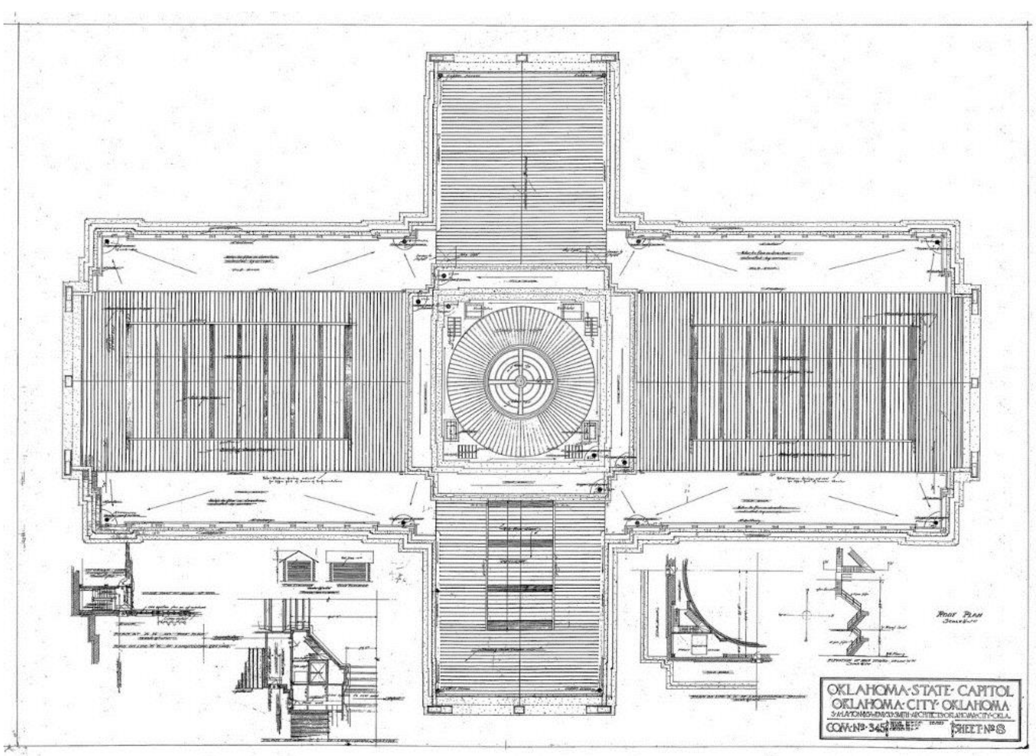


Figure 2. Roof floor plan reproduced from original drawings

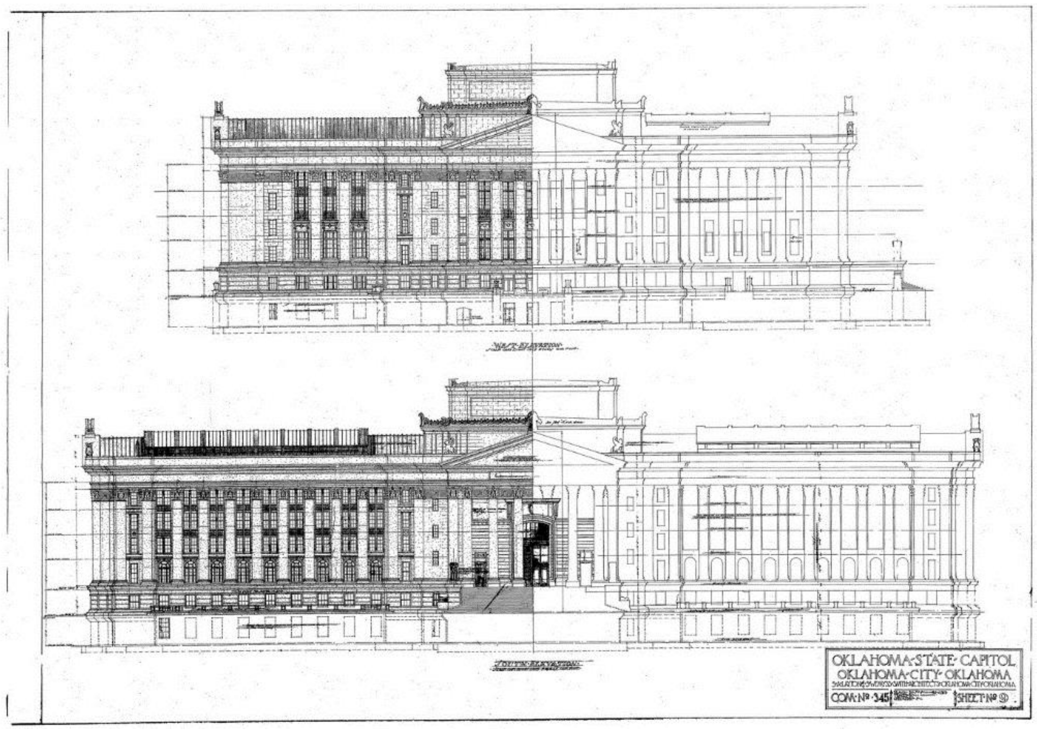


Figure 3. West and south elevations reproduced from original drawings

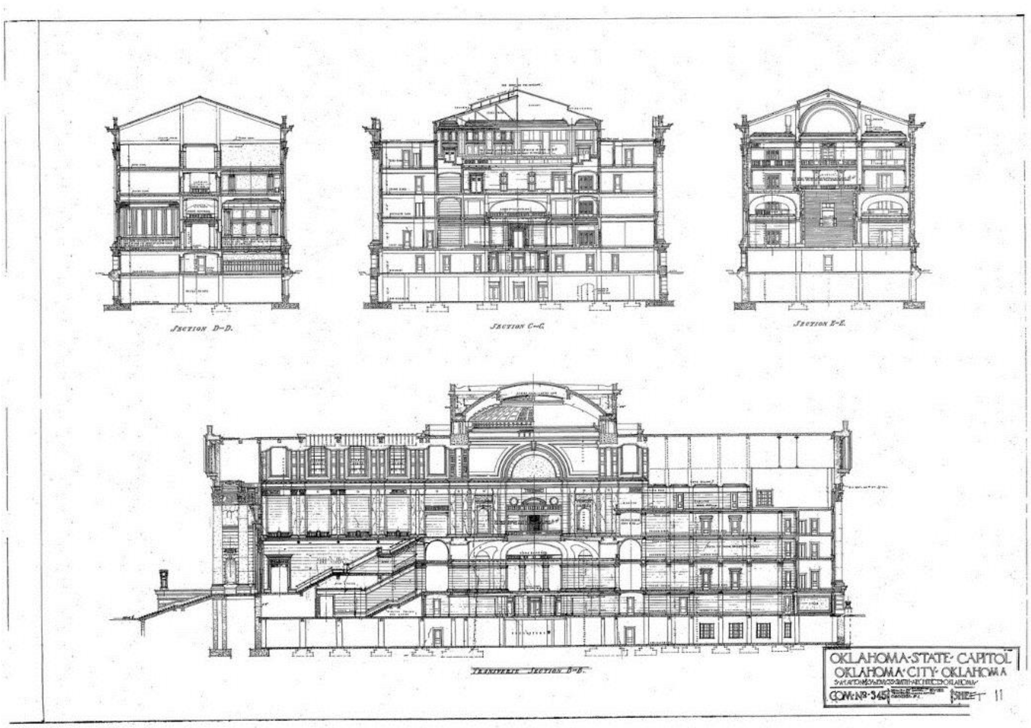


Figure 4. Building sections reproduced from original drawings

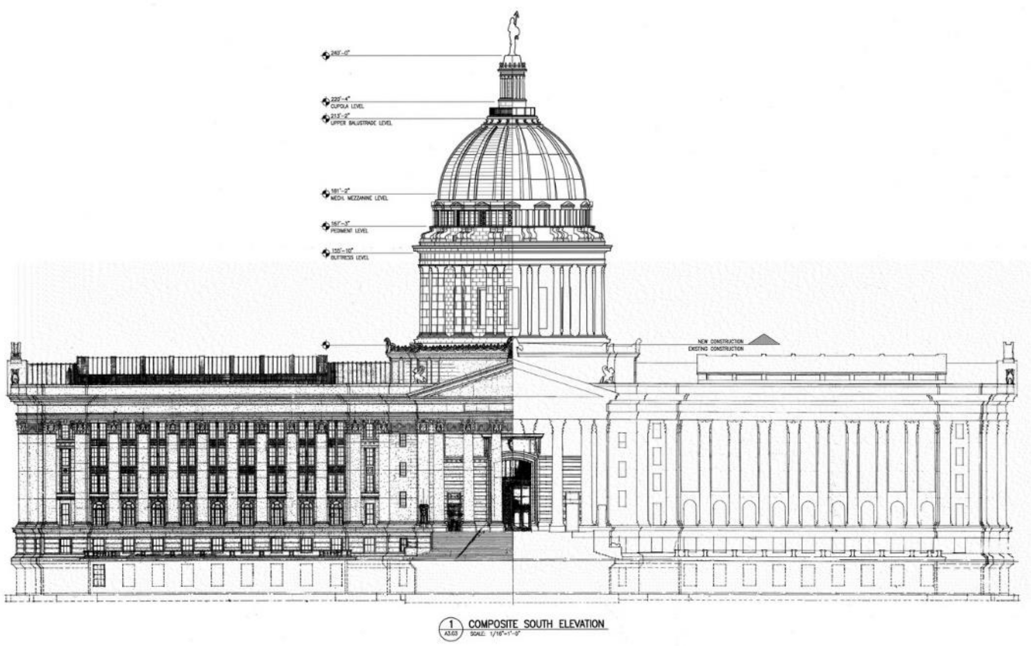


Figure 5. South elevation reproduced from 2002 drawings

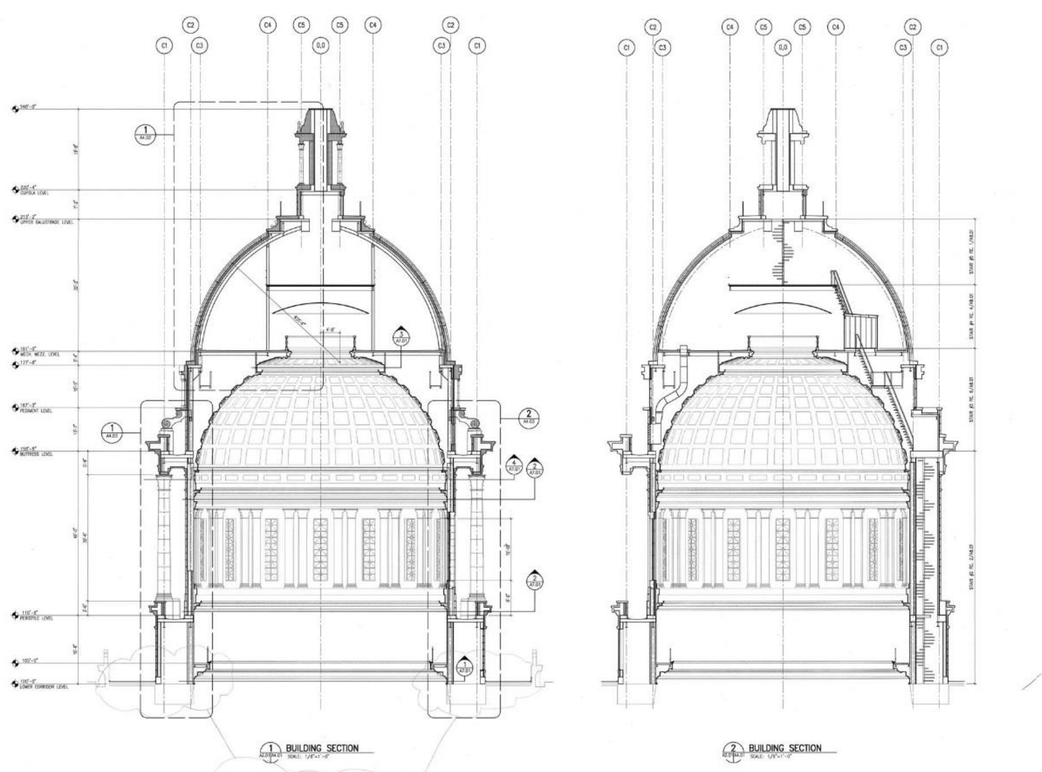


Figure 6. Dome section reproduced from 2002 drawings

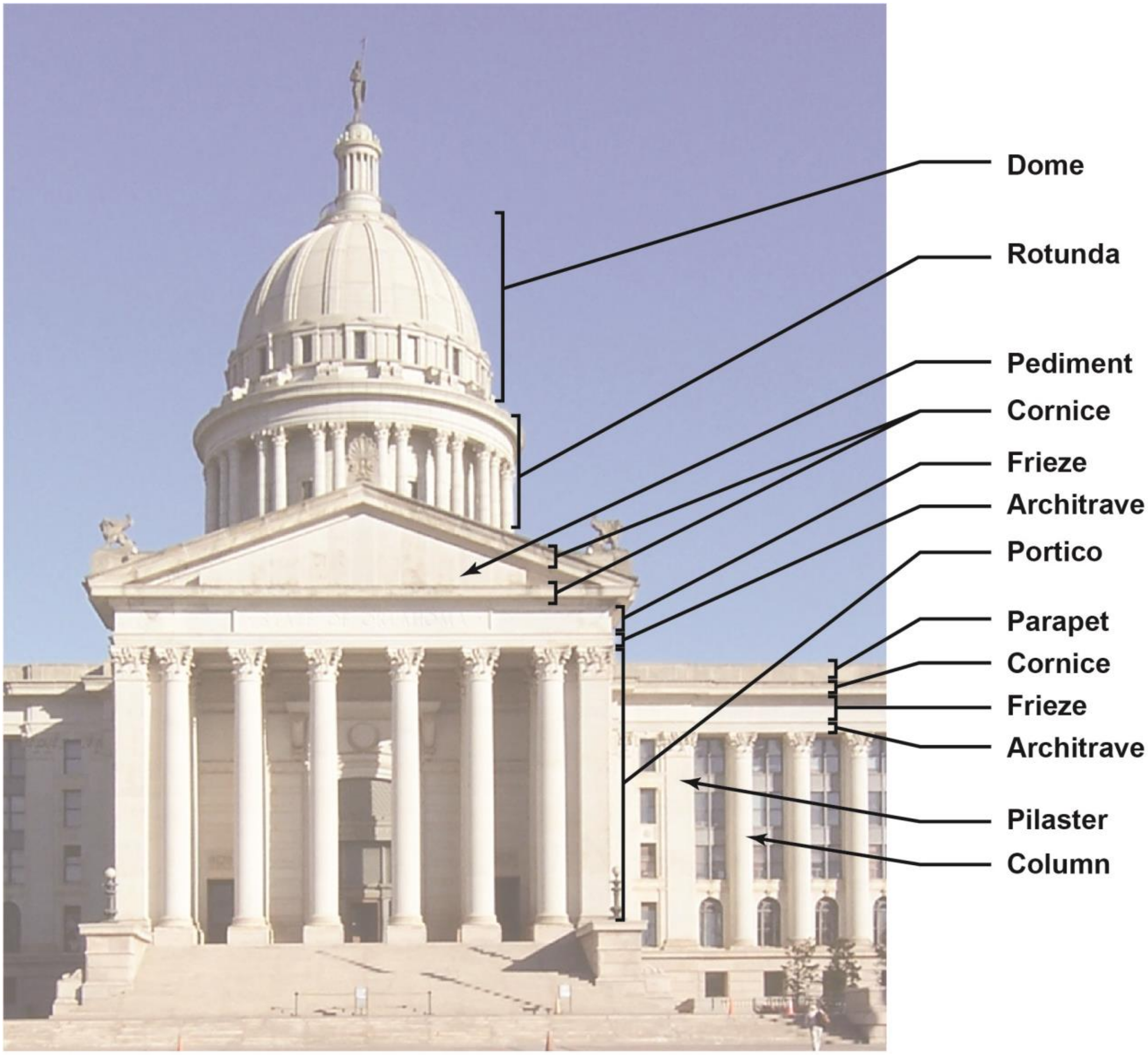


Figure 7. Annotated photograph of facade illustrating architectural terms used within this report

DOCUMENT REVIEW

To become familiar with the original exterior wall design, WJE reviewed the following documents:

- Original architectural and structural drawings prepared by Layton & Smith, Architects
- "Contract, Bond and Specifications for the Oklahoma State Capitol" (project manual) prepared by Layton & Smith, Architects, dated October 24, 1914
- Historic photographs provided MAI and OMES
- *State Capitol Building Dome Addition for the State of Oklahoma* drawings prepared by Frankfurt Short Bruza Architects Engineers Planners, dated March 5, 2001
- *State Capitol Building Historic Conditions Report* prepared by MAI (referred to as the 2010 report)

DESCRIPTION OF CONSTRUCTION AND OBSERVATIONS

The conditions described below are based on a combination of our document review, visual inspections, and field and laboratory studies.

Main Facades

Limestone

The project manual for the Capitol specifies the use of Oolitic limestone to be quarried from the northern part of Johnson County, due south of Indianapolis, Indiana. Based on our observations the color is primarily "buff," though there are some limited panels that appear to be variegated.

The exterior walls consist of multi-wythe brick masonry backup that is set into the reinforced concrete building frame and clad with limestone. The limestone is supported by the granite base course that in turn is supported by the reinforced concrete foundation. The south portico is constructed with a steel frame, and, based on original drawings, the concrete roof deck for the south wing is continuous between the concrete and steel-framed structures. With the exception of the south portico, there is no supplemental steel framing (shelf angles) in the exterior wall that supports the weight of the limestone cladding.

Based on our review of original drawings and field observations, the limestone panels were laid integrally with the brick backup wall. There are typically four courses of limestone units for each pilaster (or column) unit and two pilaster units between each floor level. The thickness of the limestone panels vary between 4 inches and 8 inches. Exterior walls built in this era were typically constructed with alternating courses of different thicknesses with the thicker units keyed into the brick backup wall. Portions of the limestone cladding are keyed into the backup, while other areas have limestone panels that are constructed of a uniform thickness and rely on mild steel strap anchors set into the brick masonry backup for lateral support. A representative wall section reproduced from the original drawings is shown in Figure 8.

The building is constructed in the neoclassical style, and the end of each wing is constructed with an entablature and pediment that is supported by a combination of solid limestone columns and limestone-clad piers (pilasters). The column and pilaster capitals are of the Corinthian style. The entablature consists of an architrave, frieze, and cornice. The architrave units are constructed from two separate units: a fascia and a soffit. The architrave spans between columns or between columns and pilasters. The limestone frieze panels are typically 4 inches thick and supported laterally at the top of each panel with mild steel strap anchors located approximately at quarter points of each unit.

The projecting limestone cornice near the top of the building is nominally 14 inches thick and is anchored at the back face of the unit with mild steel rods set into the joint between adjacent cornice units and anchored to a plate that was set integrally within the brick masonry backup. A wall section reproduced from the original drawings (Sheet 15) taken through the west pediment is shown in Figure 9.

The north- and south-facing exterior walls for the east and west wings are very similar in construction to the pediment wall areas, with the exception that the top of the exterior walls terminate with limestone-clad parapet walls that are capped with limestone copings. The parapet walls consist of 4 inch thick limestone panels and two wythes of brick masonry backup. Brick masonry piers at the back face of the parapet wall align with limestone columns (approximately at 13 foot centers) and provide lateral stability for the parapet wall. The back faces of the parapet walls are coated with several layers of paint.

The east- and west-facing exterior walls for the north and south wings are nearly identical to the east and west wings with the exception that the framing for the gabled roofs are set into the parapet wall. A wall section reproduced from the original drawings (Sheet 16) taken through the north wing is shown in Figure 10.

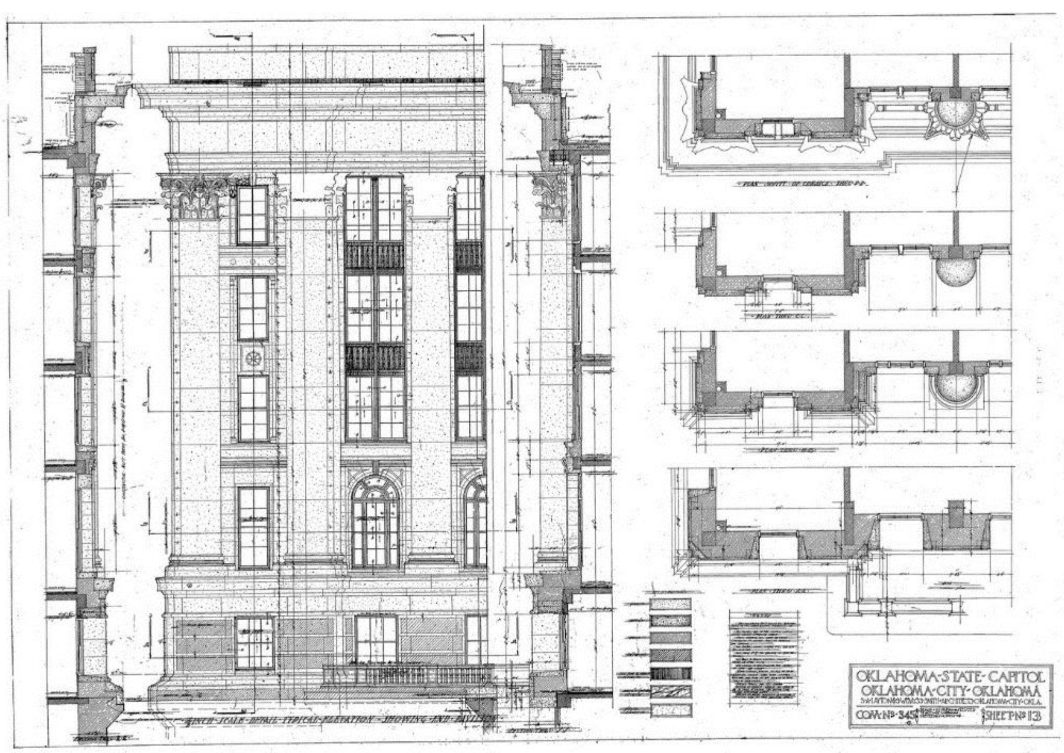


Figure 8. Detailed elevation and facade plan details reproduced from original drawings

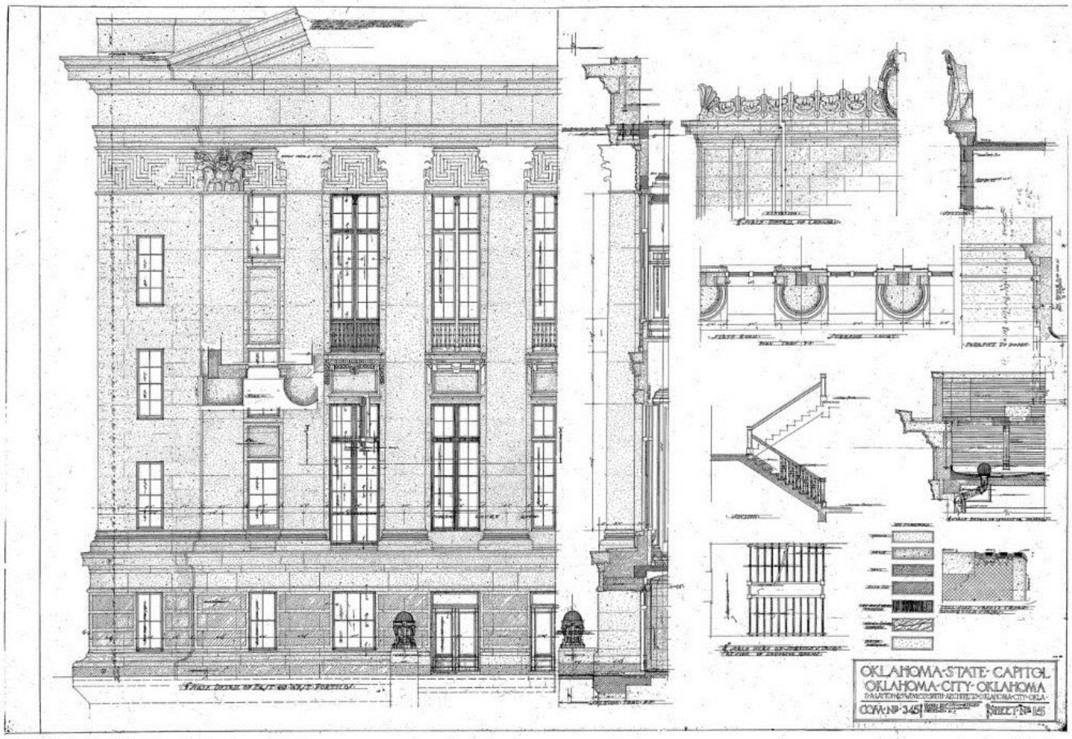


Figure 9. Detailed elevation and facade details reproduced from original drawings

Figure 10. Detailed elevation and facade details reproduced from original drawings

Representative conditions observed during our close-up inspections are described below.

1. Spalls exist at various locations throughout the building at original mild steel lateral strap anchor locations. The locations include parapet wall panels, frieze panels, ashlars in the pediment, ashlars next to limestone pilasters, and spandrel panels between the second and third floor windows.
   a. Parapet: Spalls exist at a total of seven parapet wall panels, or 4 percent of all parapet wall panels on the building (Figure 11). The spalls are located on the north, south, and east facades of the building and coincide with concealed mild steel strap anchors (Figure 12). Our visual inspection was supplemented with a survey of all parapet wall panels using a metal detector. Beyond the strap anchors that have spalled, only two or three other strap anchors were identified using a metal detector at parapet wall locations.
   b. Frieze: Spalls exist at a total of seventeen frieze wall panels, or 7 percent of all frieze wall panels on the building (Figure 13). Nearly all of the spalls at frieze panels occur on the south portico of the building and coincide with concealed mild steel strap anchors (Figure 14). With a metal detector, we randomly surveyed additional frieze panel locations and determined that "cramp" anchors generally exist at the vertical joints between adjacent panels and at approximate quarter points in the top edge of each panel.
   c. Pediment Ashlars: Spalls exist at a total of four pediment wall panels, or 3 percent of all pediment wall panels on the building (Figure 15). Spalls exist on the north and south pediment only and coincide with concealed mild steel strap anchors (Figure 16). With a metal detector, we randomly surveyed additional panel locations and determined that strap anchors exist at quarter points in the top edge of some, but not all, existing panels.
   d. Spandrels: Spalls exist at a total of three panels at the spandrel between the second and third floor windows, or 2 percent of all spandrel wall panels on the building (Figure 17). The spalls are located on the north facade of the building and coincide with concealed mild steel strap anchors (Figure 18). The spandrel consists of three panels (Figure 19). With a metal detector, we randomly surveyed additional spandrel panel locations and determined that strap anchors generally exist at quarter points in the top edge of each panel. An additional seven spalls (6 percent of all panels) exist on the north and south facades that don't coincide with metal strap anchors.
2. Cracks exist at various locations throughout the building including ashlar panels on the main facades (Figure 20), windowsills (Figure 21), frieze panels (Figure 22), and architrave units (Figure 23). There are a few isolated instances where small chips exist that are located near the edge or corner of a panel.
3. Cracks and incipient spalls exist at third floor windowsills (Figure 24 and Figure 25). Spalls exist at nine windowsills, or 22 percent of all windowsills on the north and south facades.
4. There are widespread areas throughout the building where mortar bond failure exists between limestone units (Figure 26).
5. The mortar throughout the building has been coated with a cementitious coating on the outside face of the joints and adjacent limestone units (Figure 27). There are limited areas where mortar is missing or washed out, particularly at upper levels of the dome platform (Figure 28).
6. Exfoliation exists at a few limestone panels, primarily at the frieze above the south portico (Figure 29 and Figure 30) and also at third floor windowsills.
7. Limited areas of limestone exist near outside building corners and the top of the exterior wall that are out of plane on the order of 1/4 inch. There are some areas at the top of parapet walls where panels are outwardly displaced between 1/8 and 1/4 inch.

8. Dutchman repairs, consisting of a small piece of limestone that is pinned to the parent panel, are generally limited to the column capitals and other ornamental areas of the facade. A few small debonded dutchman repairs were removed during our inspection. There is little evidence that previous repairs have included installation of dutchman units on the exterior walls of the building, which suggests that these dutchman repairs likely are from original construction (Figure 31).
9. Some of the limestone panels have ferrous mineral inclusions at the outside face of the panel (Figure 32). The inclusion has caused iron oxide (brownish) stains to develop on the outside face of the building.
10. Seams exist in limestone panels throughout the building. Seams can be open or naturally filled and in limestone, frequently have contrasting whitish color (Figure 33). In most instances the presence of a seam in limestone is negligible with respect to its strength and long-term performance.
11. MAI and OMES reported that a sealer was applied to the outside surface of the limestone as part of the 1980s repointing project.

Figure 11. Example of limestone spall observed at parapet wall

Figure 12. Close-up view of limestone spall location coincident with original strap anchor

Figure 13. Example of limestone spall at frieze panel

Figure 14. Close-up view of limestone spall coincident with original strap anchor

Figure 15. Example of limestone spall at pediment ashlar units

Figure 16. Close-up view of limestone spall at pediment ashlar unit coincident with original strap anchor

Figure 17. Example of limestone spall at spandrel panel

Figure 18. Example of limestone spall at spandrel panel

Figure 19. Example of limestone spall at spandrel panel

Figure 20. Example of cracking at ashlar limestone panel on main facade

Figure 21. Example of cracked limestone at windowsill

Figure 22. Example of cracked limestone at frieze panel

Figure 23. Example of cracked limestone at architrave unit

Figure 24. Limestone spall at third floor windowsill

Figure 25. Close-up view of limestone spall at third floor windowsill

Figure 26. Mortar bond failure between limestone units

Figure 27. Cementitious coating at mortar joints

Figure 28. Washed-out mortar joint

Figure 29. Exfoliation of limestone units

Figure 30. Exfoliation of limestone units

Figure 31. Area of limestone dutchman repair removed during inspection

Figure 32. Mineral inclusion in limestone causing iron oxide staining

Figure 33. Seam within limestone unit

Granite

Granite for the Capitol was supplied from an area known as the "Ten-Acre Rock" that is located about 12 miles northwest of Tishomingo near Troy, Oklahoma. The pink and reddish granite deposit near Troy is fine-grained, whereas the material closer to Tishomingo is coarse-grained. An estimated 50,000 cubic feet of granite was quarried for the Capitol, and the granite is generally limited to first floor level and exterior wall panels in the light wells on the north and south facades of the building.

1. Cracks in granite units are generally limited to panels located near the outside building corners (Figure 34 and Figure 35).
2. Corrosion stains exists on granite units located near the top of the light wells. The staining is the result of abandoned anchors that may have previously supported steel grates at the top of the light wells (Figure 36 and Figure 37).
3. Locations with washed-out mortar are significantly higher at granite areas of the facade compared to limestone facade areas. Granite areas where mortar is missing exist primarily at upward-facing joints within the granite watertable above the first floor and at outside building corners on the building (Figure 38 and Figure 39).

Figure 34. Crack within granite unit

Figure 35. Crack within granite unit

Figure 36. Corrosion staining at abandoned anchors at light wells

Figure 37. Close-up view of abandoned anchors

Figure 38. Washed-out mortar in granite units

Figure 39. Washed-out mortar in granite units

Light Well Walls

Light wells exist on the north and south walls of the east and west wings and on the east and west walls of the north wing. Consistent with the exterior wall construction at the first floor level, the building facade below grade is predominantly clad with Oklahoma pink granite. The opposite wall of the light well consists of a continuous reinforced concrete foundation wall that is capped at grade level with a granite balustrade. The balustrade is constructed with a continuous top and bottom rail and has regularly spaced granite piers and balusters.

1. A coating has been applied to the exposed surfaces of the below grade reinforced concrete walls (Figure 40).
2. The inside face of the concrete foundation wall (within the light well) was originally clad with mortar-set 1/4 inch thick quarry tile (Figure 41). There are presently a few areas where the original tile is delaminating from the inside face of the concrete wall.
3. Cracks and previously removed spalls were observed extensively throughout the inside face of the concrete foundation walls (Figure 42 through Figure 44).

Figure 40. Coating applied to light well walls

Figure 41. Delaminating tile at light well

Figure 42. Cracks at foundation walls

Figure 43. Cracks and spalls at foundation walls

Figure 44. Cracks and spalls at foundation walls

Mortar

Specifications

Based on our laboratory petrographic examination of mortar samples taken from the building, the original mortar is consistent with the original project specifications and consists of portland cement, sand, and lime.

The specifications indicate that limestone setting mortar was to be 1 part non-staining cement, 2 parts sand, and tempered with lime paste. The specifications indicate that limestone pointing mortar shall be 1 part non-staining cement (presumed to be referring to white portland cement) and 1 part white sand.

Mortar Analysis

Petrographic analysis was conducted of original setting mortar, remnants of the likely original pointing mortar attached, and repointing mortar removed during the investigation in accordance with the petrographic examination portion of ASTM C1324, *Standard Test Method for Examination and Analysis of Hardened Masonry Mortar*, using the appropriate methods and procedures outlined in ASTM C856, *Standard Practice for Petrographic Examination of Hardened Concrete*, which also applies to mortar. Thin sections were prepared from each mortar to assess the composition, condition, and microstructure.

Original Setting Mortar

The fresh fracture surface of the mortar was light gray with a pink tint. The mortar was fairly dense, firm and non-friable (not crumbly). The mortar was light pinkish gray on fresh fracture surfaces. Aggregates and paste were fairly uniformly distributed (Figure 45).

The paste/binder system was portland cement and hydrated lime. The extent of cement hydration was nearly complete. Residual portland cement particles were infrequent and were typically small in size. The abundance of calcium hydroxide in the non-carbonated paste was high; crystal characteristics suggest that most of the calcium hydroxide is secondary. Entrapped air content was estimated at 5 to 8 percent; however, the mortar did not appear to be intentionally air-entrained.

The fine aggregate was a natural sand composed of rounded to angular, mainly equant, particles of quartz/quartzite, feldspar, and minor to trace amounts of chert, sandstone, and iron oxides (Figure 46 and Figure 47). The sand was generally well-graded. Maximum particle size was 1.2 mm; it is estimated 95 to 98 percent of particles pass through a No. 16 sieve (consistent with ASTM C144, *Standard Specification for Aggregate for Masonry Mortar*). Sand content ratio appeared normal (consistent with ASTM C270, *Standard Specification for Mortar for Unit Masonry*).

The flat surfaces were typically coated with a thin layer of secondary carbonate and dark-colored debris deposits. The underlying paste was carbonated. The optical characteristics of the paste in the interior region of the mortar are consistent with extensive water leaching and re-crystallization. Micro-crystalline secondary deposits are locally abundant in the air voids and in the paste (Figure 49).

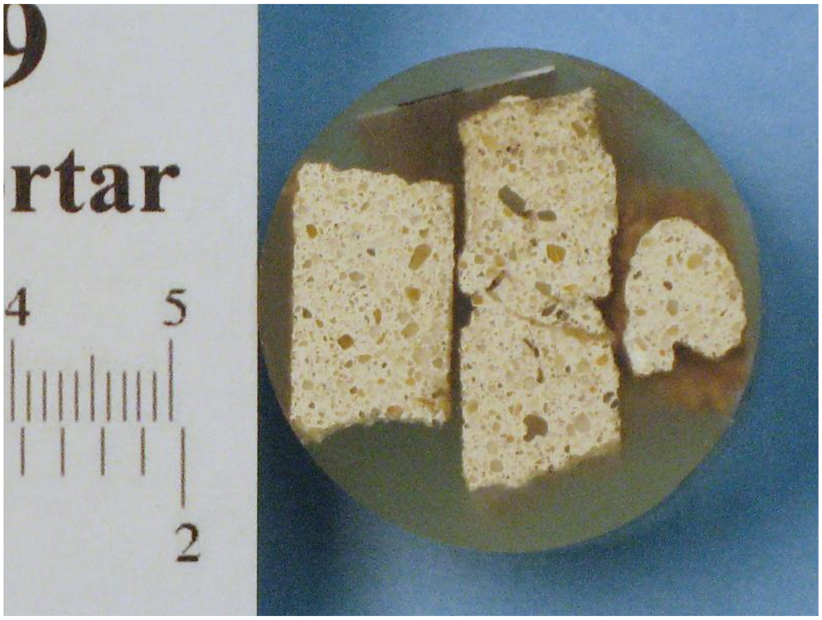


Figure 45. Original setting mortar, lapped cross sections showing overall appearance.

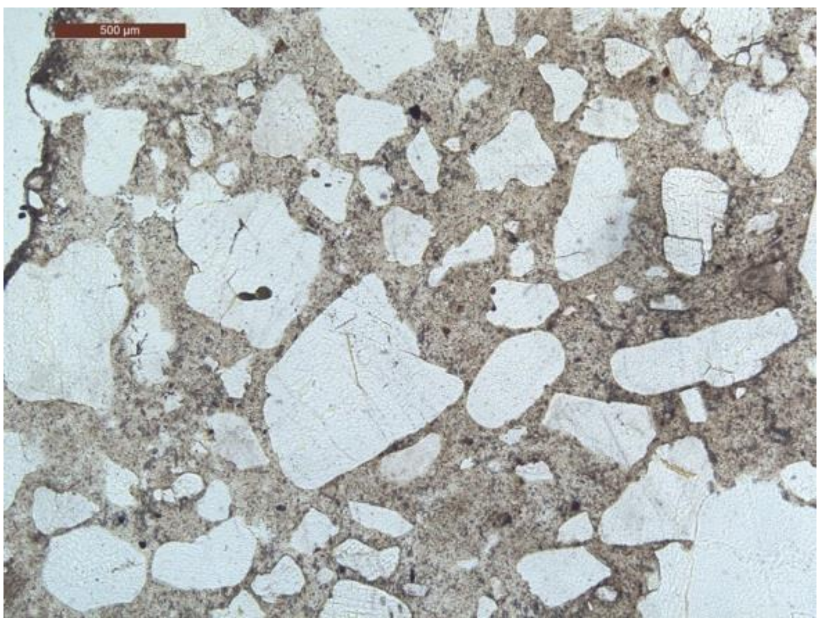


Figure 46. Original setting mortar. Thin-section micrographs show sand (large particles) and paste/binder. Plane-polarized light.

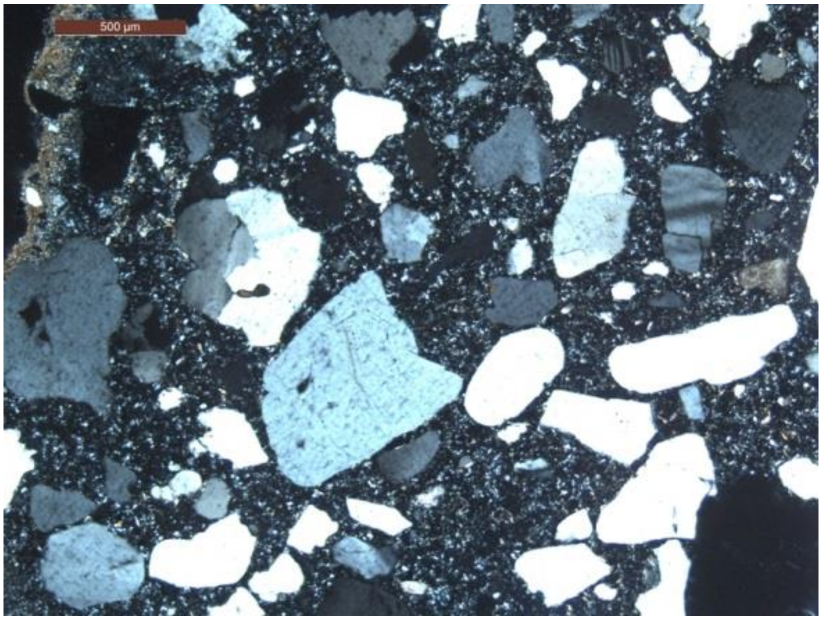


Figure 47. Original setting mortar. Thin-section micrographs show sand (large particles) and paste/binder. Cross-polarized light.

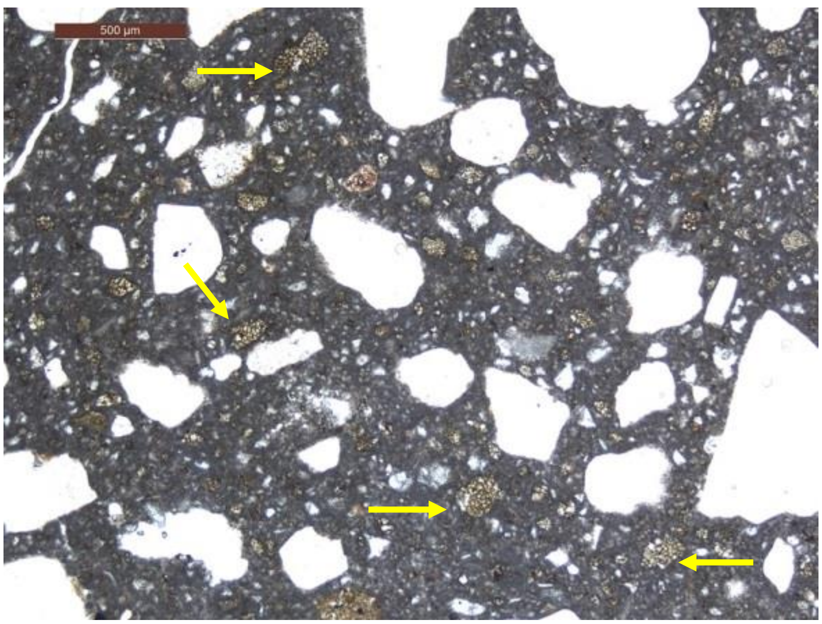


Figure 48. Original setting mortar. Thin-section micrographs show low sand volume and high binder volume of likely original pointing mortar. Arrows show typical large residual portland cement particles. Plane-polarized light.

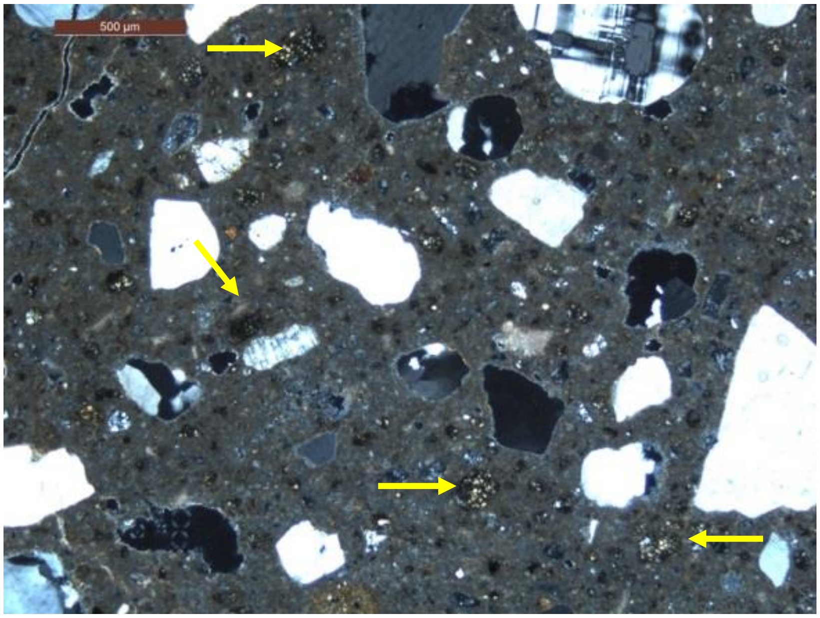


Figure 49. Original setting mortar. Thin-section micrographs show low sand volume and high binder volume of likely original pointing mortar. Arrows show typical large residual portland cement particles. Cross-polarized light.

Original Pointing Mortar

Remnants of an earlier mortar, likely the original pointing mortar, was adhered to the interior portion of the pointing mortar sample analyzed. The mortar was medium gray and consisted of siliceous sand dispersed in portland cement and hydrated lime paste/binder. The mortar was under-sanded, based on the distance between aggregate particles, which is consistent with the original specified cement-rich proportions (Figure 50 and Figure 51). The unhydrated and partially hydrated portland cement particles were large and typical of coarsely ground portland cement produced in the early 1900s. The extent of cement hydration was moderately advanced. The paste contained frequent shrinkage cracks, which are typical in under-sanded mortar. Cracks lined with calcite were observed near the edges of the mortar. The paste was partially carbonated.

Repointing Mortar

The depth of the repointing mortar was approximately 1/2 inch. The repointing mortar was light pink-gray, firm, and locally somewhat porous. Constituents were non-uniformly distributed; sand-rich regions and a few small cementitious lumps were observed.

The paste/binder system was portland cement and hydrated lime (Figure 50 and Figure 51). The extent of cement hydration was far advanced; residual cement particles were infrequent. The paste was fully carbonated. Entrapped air content was estimated at 5 to 10 percent; however, the mortar did not appear to be intentionally air-entrained.

The fine aggregate was a natural sand composed of rounded to angular, mainly equant, particles of quartz/quartzite, feldspar and minor to trace amounts of chert, iron oxides, and garnet (Figure 48 and Figure 50). Most sand particles were smaller than 1 mm (estimated 100 percent passing through a No. 16 sieve).

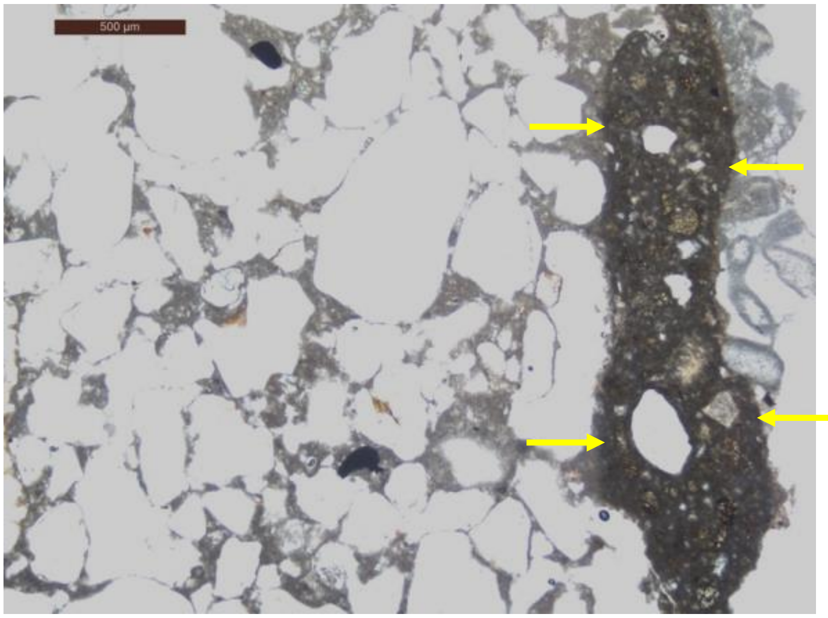


Figure 50. Pointing mortar. Thin-section micrographs show sand (large particles) and binder. Thin layer of adhered limestone on right. Likely original pointing mortar layer between arrows. Plane-polarized light.

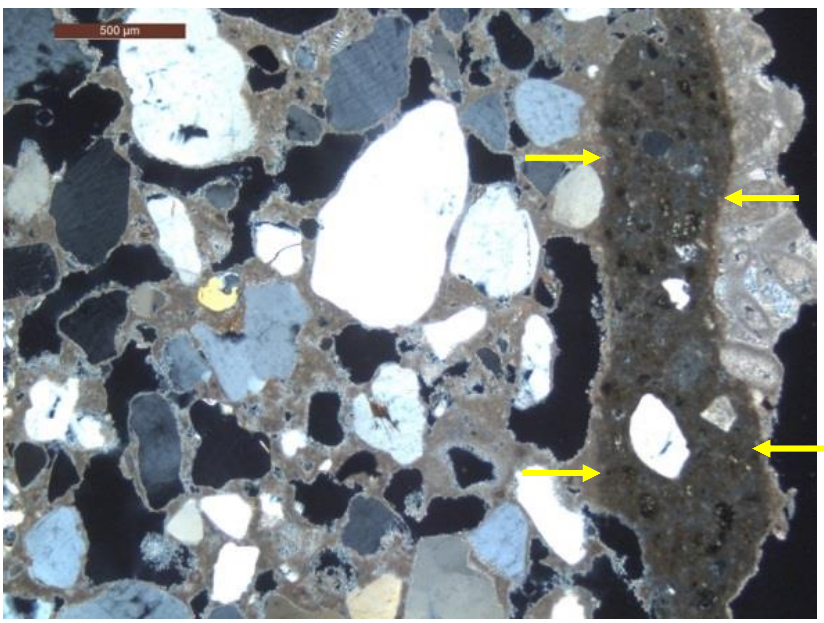


Figure 51. Pointing mortar. Thin-section micrographs show sand (large particles) and binder. Thin layer of adhered limestone on right. Likely original pointing mortar layer between arrows. Cross-polarized light.

Coating Analysis

A white coating had been applied to the mortar joints in the limestone masonry (Figure 52). The coating was likely applied by brush and frequently extends on to the adjacent limestone. A sample of the white coating applied to the mortar joints was analyzed to identify any polymeric binder that may have been present in the coating. The samples were extracted with a solvent suitable for the isolation of the coatings' polymeric binder components. The collected residues were subjected to Fourier transform infrared (FTIR) spectroscopic analysis. The analysis identified only trace hydrocarbon and ester functionality, indicating that the coating was primarily inorganic.

Figure 52. White coating applied to mortar joint and adjacent limestone

Staining

During visual survey of the facade, the following notable soiling and staining conditions were observed on the exterior facades.

- Dark orange staining of the limestone at the vertical face of the window sill (Figure 53)
- Light orange steaks of the limestone at the columns and pilasters (Figure 54)
- Orange staining of the limestone below the punched windows on the south facade (Figure 55)
- Dark orange staining at the south portico with lighter vertical streaks (Figure 56)
- Dark horizontal streaks on the limestone columns (Figure 57)
- Dark staining of the limestone largely biological growth at column bases and limestone molding above the granite (Figure 58 and Figure 59)
- Dark staining of the limestone from biological growth at parapets (Figure 60)
- Dark staining of limestone underneath window lintels (Figure 61)
- Dark staining and orange staining of limestone balusters (Figure 62)
- Dark biological growth on the granite watertable (Figure 63)
- Iron stains of the granite as a result of the oxidation of ferrous mineral inclusions (Figure 64)
- Iron stains on the granite as a result of surface applied steel anchors and grates (Figure 65 and Figure 66)
- Iron stains on the granite and limestone entrance steps as a result of steel stanchions (Figure 67)
- Iron oxide staining of granite steps from steel railing (Figure 68)

Figure 53. Dark orange staining of limestone at window sill (above)

Figure 54. Light orange steaks at limestone columns (right)

Figure 55. Orange staining of limestone below punched windows (left)

Figure 56. Streaky orange staining of limestone at the south portico (above)

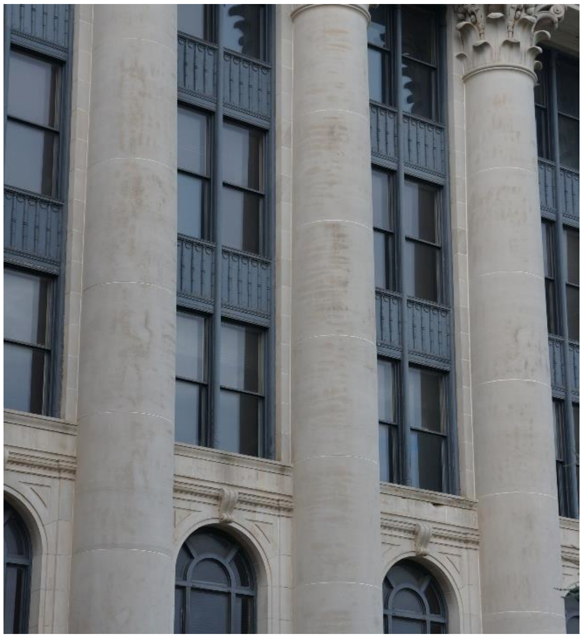


Figure 57. Dark horizontal streaks on limestone columns (left)

Figure 58. Soiling of limestone column bases (above)

Figure 59. Soiling at limestone column bases above granite

Figure 60. Dark staining at limestone parapets

Figure 61. Dark staining below limestone lintels

Figure 62. Stained limestone balusters

Figure 63. Biological growth on granite watertable

Figure 64. Staining from ferrous mineral inclusions

Figure 65. Staining of granite from surface-applied metal appurtenances

Figure 66. Staining of granite and limestone from surface-applied metal appurtenances

Figure 67. Staining of granite from steel stanchions at entrances

Figure 68. Staining of granite stairs from steel railing

Orange Staining Cleaning Trials

Cleaning trials were conducted of the orange staining on the east wall of the south portico as listed in Table 1 (Figure 69).

A cleaning trial using very low-pressure water misting was conducted of the orange staining on the south facade to the west of the portico. While the cleaning was unsuccessful at removing the soiling, a drying pattern emerged related to the orange streaks subsequent to the cleaning trials (Figure 70 and Figure 71).

Table 1. Cleaning Trials - Orange Staining

Trial	Cleaning Chemical	Cleaner Description	Dwell time
A1	D/2 Biological Solution (diluted 1:3)	Liquid quaternary ammonium compound pH 9.5	15 minutes
A2	American Building Restoration Products X-190	Oxalic acid	15 minutes
A3	Chemique Artisan Light Duty Rust Remover	Oxalic acid, surfactant	15 minutes
A4	Very low pressure water misting		6 hours
A5	Klean Strip KS-3 Premium Stripper	Methylene chloride, methanol. Stoddard solvent	15 minutes

None of the trials significantly reduced or removed the orange staining.

Biological Growth Cleaning Trials

Cleaning trials of the dark biological staining on the limestone were completed on the backside of the platform at the northwest corner of the building as shown in Table 2 (Figure 72 through Figure 75).

Table 2. Cleaning Trials - Biological Growth

Trial	Cleaning Chemical	Cleaner Description	Dwell time
B1	D/2 Biological Solution (concentrated)	Liquid quaternary ammonium compound pH 9.5	15 minutes
B2	D/2 Biological Solution (diluted 1:3)	Liquid quaternary ammonium compound pH 9.5	15 minutes

Both samples successfully reduced the amount of biological growth.

Figure 69. Area of limestone cleaning trial

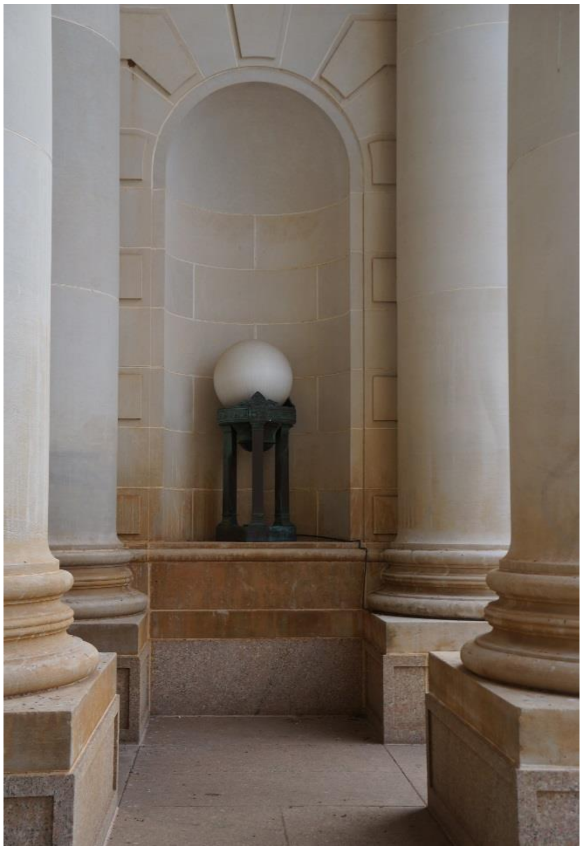


Figure 70. Area of limestone cleaning trials at south portico

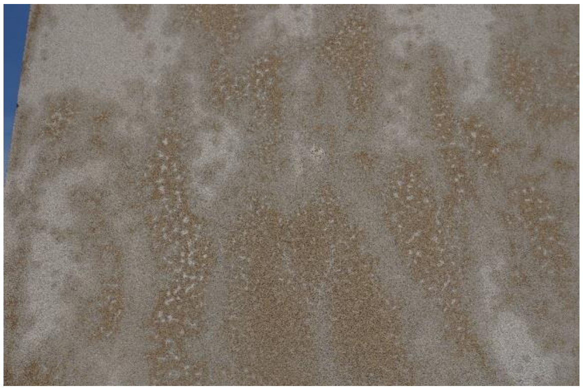


Figure 71. Close-up view of cleaning trial area

Figure 72. Area of trial cleaning at limestone parapet before application of cleaner

Figure 73. Area of trial cleaning at limestone parapet after application of cleaner

Figure 74. Area of trial cleaning at limestone parapet before application of cleaner

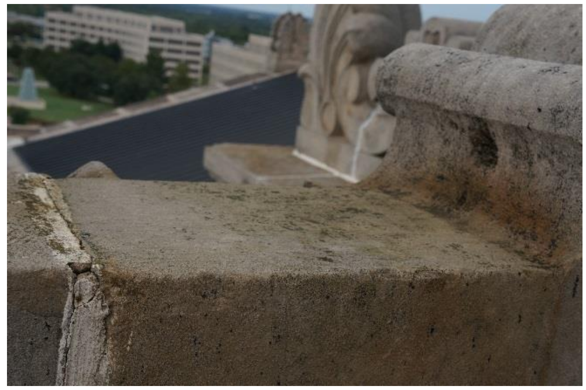


Figure 75. Area of trial cleaning at limestone parapet after application of cleaner

Laboratory Analysis

Since the trials of cleaning the orange staining were unsuccessful, three 3 inch diameter cores of orange-stained limestone were removed for laboratory analysis (Figure 76). Two small chips were collected from the surface and analyzed using scanning electron microscopy with energy dispersive x-ray spectroscopy (SEM/EDS) to determine the elemental composition of the discolored surface (Figure 77). One chip encompassed both discolored and non-discolored areas. The elemental analysis of the non-discolored area indicated the presence of calcium, carbon, and oxygen, with very minor to trace signatures from other elements in areas including magnesium, aluminum, silicon, phosphorus, sulfur, chlorine and iron (Figure 78 and Figure 79). In contrast, the discolored surface shows significant signature from silicon, aluminum, and iron, with minor signature due to sodium, phosphorus, sulfur, chlorine, magnesium and titanium, along with potassium and zinc in areas (Figure 80 and Figure 81). The discolored surface is associated with increased levels of silicon, iron, aluminum, titanium, sodium, and other elements. These elements are likely a result of the previous application of a clear penetrating sealer.

Figure 76. Area of limestone core

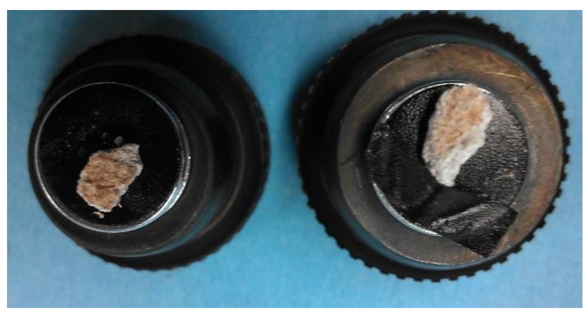
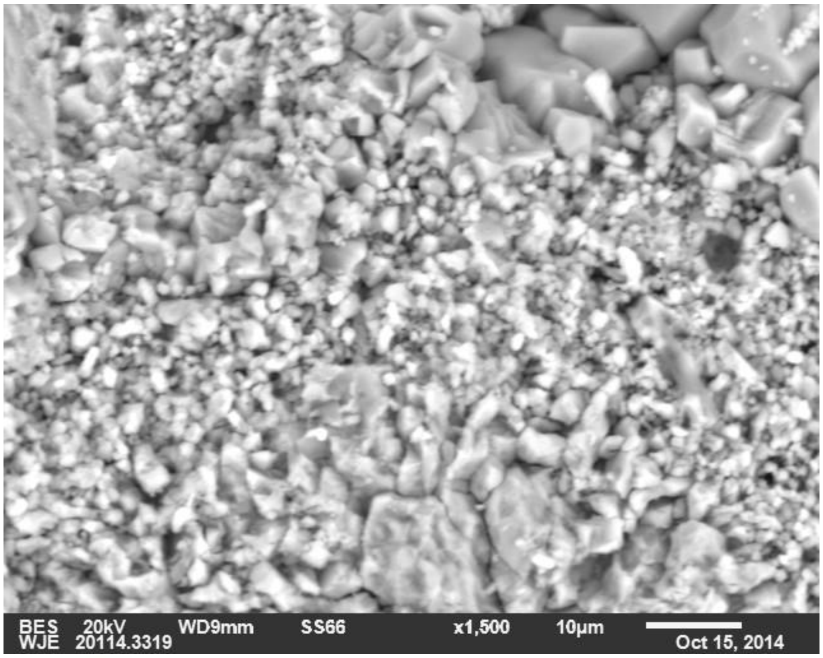


Figure 77. Photograph of the two limestone surface chips analyzed



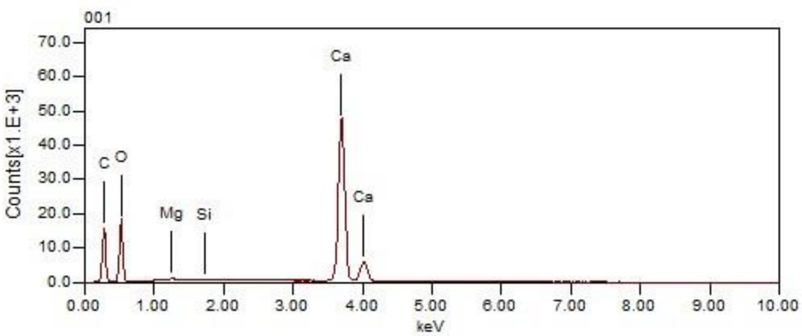


Figure 78. Backscattered electron micrograph and area EDS spectrum of a non-discolored area of the limestone surface

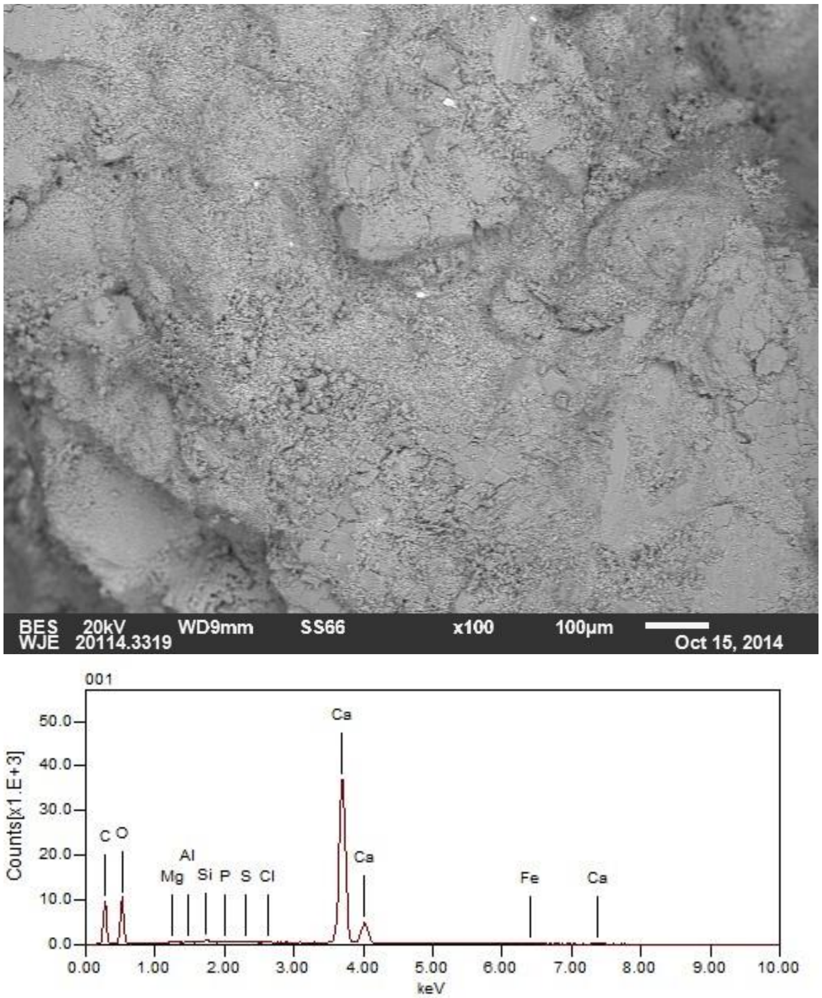


Figure 79. Backscattered electron micrograph and area EDS spectrum of a non-discolored area of the limestone surface

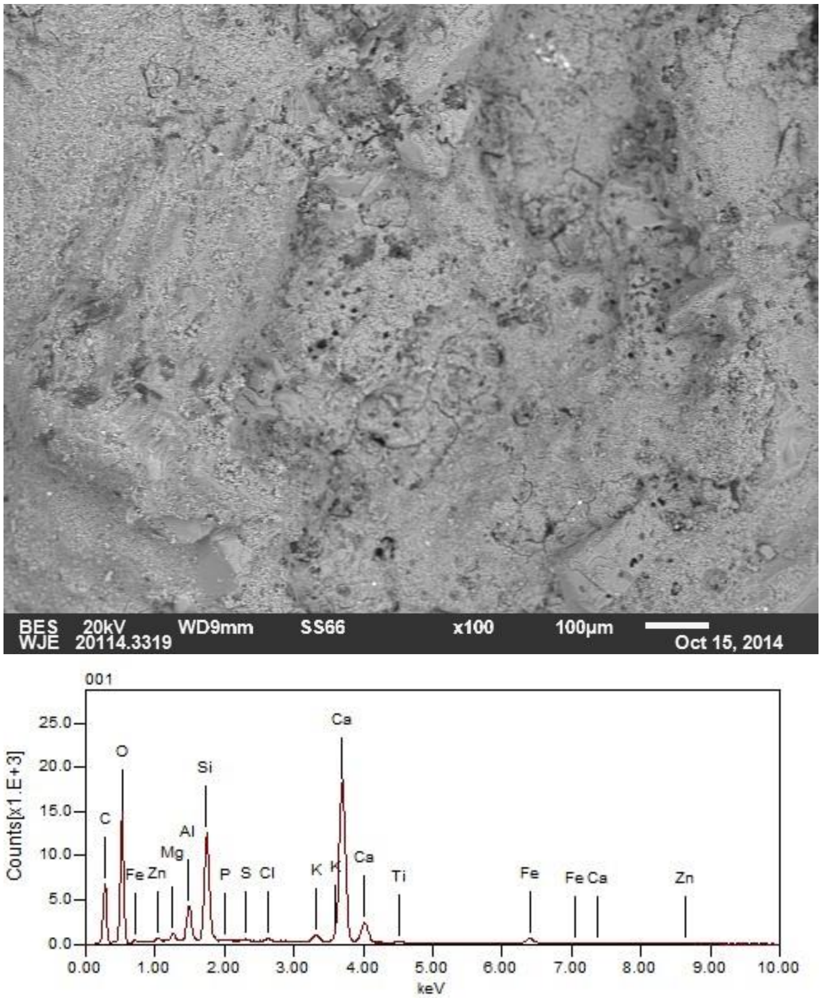


Figure 80. Backscattered electron micrograph and area EDS spectrum of a discolored area of the limestone surface

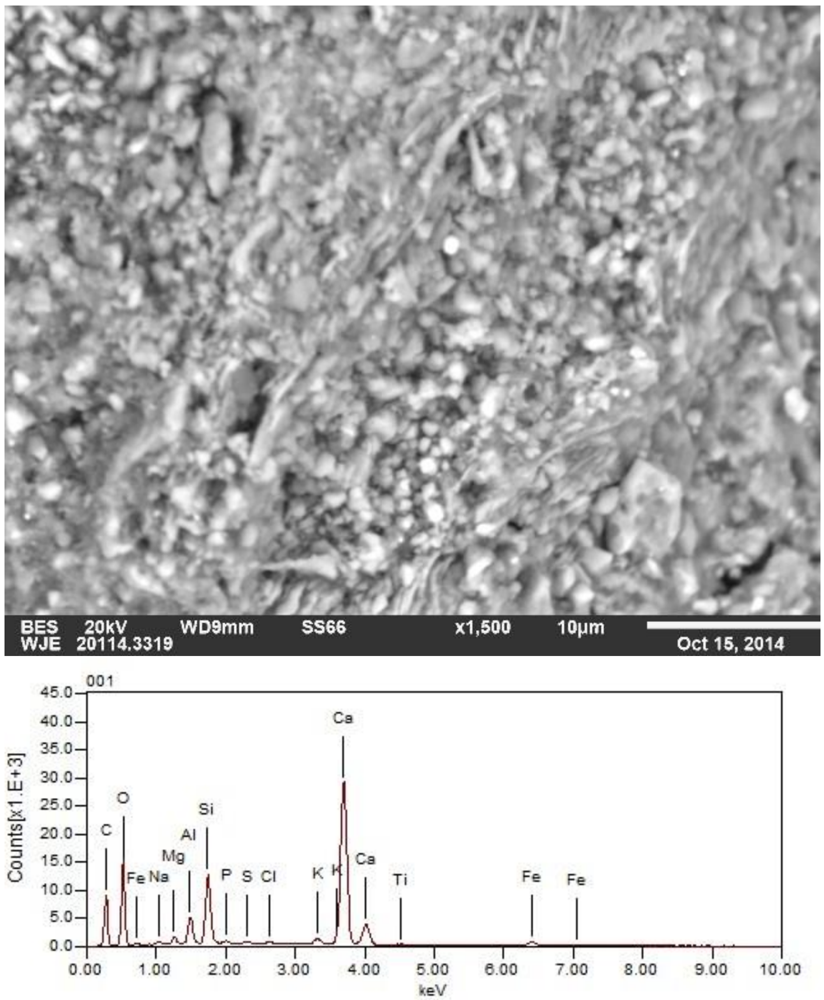


Figure 81. BE micrograph and area EDS spectrum of a discolored area of the limestone surface

Roof Facades

Brick Masonry, Limestone Cornice, and Steel Lintels

The exterior parapet walls on the north and south facades of the building are typically two wythes thick and clad with limestone. The exterior walls of the Senate and House chambers (east and west wings respectively), based on conditions observed at inspection openings, are also two wythes thick.

1. The back face of exposed parapet walls are painted (Figure 82). Based on discussions with DCAM, we understand that the back face of the parapet walls was last painted approximately fifteen years ago. Based on conditions observed at inspection openings in the parapet walls, there is at least one additional layer of paint below the exposed coating.
2. The back face of the limestone cornice is visible just below the copper gutter. Spalls and cracked limestone (Figure 83) exist at twenty-nine locations at the back face parapet walls, or approximately 26 percent of cornice units on the north and south facades. The spalls and cracks align closely with the joint between adjacent coping units. Based on inspection openings made in the back face of the brick masonry parapet wall (below the cornice), the cracks and spalls coincide with the location of mild steel rods that provide support for the cornice to resist overturning. The steel rods are 1-1/8 inch diameter and are anchored to steel beams located near the top of the exterior limestone columns (top of the fifth floor level).
3. Spalled and cracked brick masonry exists above the Senate and House chambers clerestory windows (Figure 84).
4. Diagonal and vertical cracking exists in the back face of brick masonry walls (Figure 85). The cracks generally align closely with scuppers in the upper half of parapet walls, brick masonry piers at the lower half of parapet walls, and lintels above clerestory windows for the legislative chambers.

Figure 82. Overall view of typical parapet wall

Figure 83. Close-up view of spalling and cracking at back face of parapet wall

Figure 84. Close-up view of spalling and cracking of brick above clerestory windows

Figure 85. Cracking at back face of masonry walls

Windows

1. The exterior clerestory windows for the House and Senate chambers have painted steel frames and sash with single-pane fixed glass.
2. The House and Senate windows are nearly identical, with the exception that the Senate window openings are approximately 2 feet 3 inches wide, and the House window openings are approximately 6 feet 9 inches wide (Figure 86 and Figure 87).
3. The perimeter sealant is in fair condition. No signs of adhesive or cohesive failure were observed.
4. The roof flashings terminate at the windowsill for both the House and Senate chambers windows. Corrosion stains exists on exposed portions of the sill (Figure 88 and Figure 89).

Figure 86. Window opening at House chamber

Figure 87. Window opening at Senate chamber

Figure 88. Corrosion staining at clerestory windowsill

Figure 89. Corrosion staining at clerestory windowsill

Interior Attics

Each wing has an attic between the fifth floor ceiling and the gable roof framing. The back face of each end wall consists of common brick masonry that serves as the backup wall for the limestone-clad pediment.

Review of Construction Photos and Original Drawings

Photographs provided to us from December 1915 and March 1916 depict the original construction of the gable walls (Figure 90 and Figure 91). The east, north, and west gable walls were constructed with brick masonry and directly tied to the reinforced concrete building frame. The south gable wall is constructed of freestanding brick masonry supported by a structural steel frame, which projects from the concrete building frame and creates an open portico at the south entry (Figure 92). The south pediment was constructed with thick limestone units that were originally designed to receive an *in situ* carving that ultimately was never completed (Figure 93). The south gable wall serves as backup for the south pediment, as shown on Sheet 14 of the original drawings (Figure 94).

The following was observed during our inspection of the attic spaces behind each gable.

South Gable

- There are temporary steel cable tiebacks still in place from original construction (Figure 95 and Figure 96). This is evidence that the gable was constructed as a freestanding masonry wall until it reached a point where the top of the wall could be tied back to the reinforced concrete structure.
- There are exposed metal anchors that were put in place to laterally support projecting limestone at the top of the pediment (Figure 97). There appear to be two anchors per stone that likely engage the top of each stone unit.
- Brick corbels within the gable wall provide support for the concrete roof beams and the corbel for one of the beams is cracked (Figure 98).
- There are metal through-bolt heads on the interior side of the masonry gable wall (Figure 99). These may be the anchors that tie back the large limestone panels of the pediment that were to be carved in situ.
- The flooring of the attic between the concrete frame and pediment wall is a heavy steel assembly (Figure 100) from which the south portico ceiling (soffit) is hung (Figure 101).

West Gable

- Exposed metal anchors (similar to the south gable) exist at the back face of the gable wall that provide lateral support for the projecting limestone at the top of the pediment (Figure 102 and Figure 103).
- The brick masonry gable wall is built outboard of the reinforced concrete columns (Figure 104). At these locations, there is cracking that has opened up between the columns and brickwork (Figure 105). Mechanical ties between the brickwork and concrete frame were not observed.
- Gypsum panels exist within the original House chamber skylight openings. Cracks exist in a few of the gypsum panels. (Figure 106).

North Gable

- Exposed metal anchors (similar to the south gable) exist at the back face of the gable wall that provide lateral support for the projecting limestone at the top of the pediment (Figure 107).
- The brick masonry gable wall is built outboard of the reinforced concrete columns. Mechanical ties between the brickwork and concrete frame were not observed.

East Gable

- This gable wall differs from the other gable walls in that the inside face of the wall is finished with rough plaster. Exposed metal anchors (similar to the south gable) are visible at the inside face of the plaster finish (Figure 108).
- The brick masonry gable wall is built outboard of the reinforced concrete columns. Metal anchors laid within the brickwork partially wrap and engage the concrete columns (Figure 109).

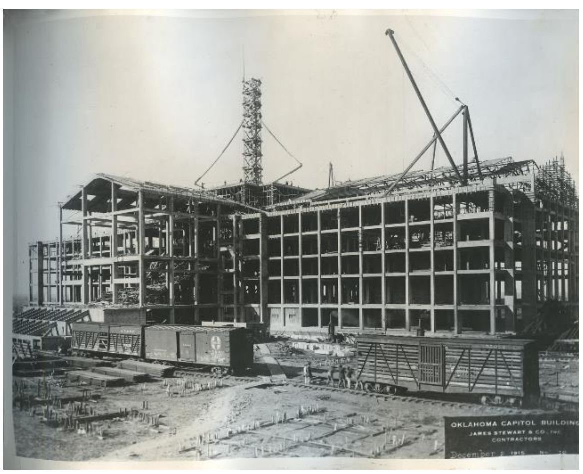


Figure 90. Construction photograph dated December 2, 1915, taken from the southeast with south gable at left and east gable at right. In this photo the reinforced concrete columns are formed in wood.

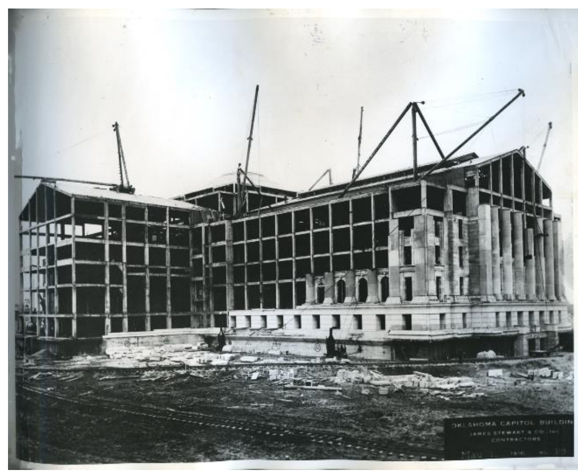


Figure 91. Construction photograph dated March 1, 1916, taken from the northwest with north gable at left and west gable to the right

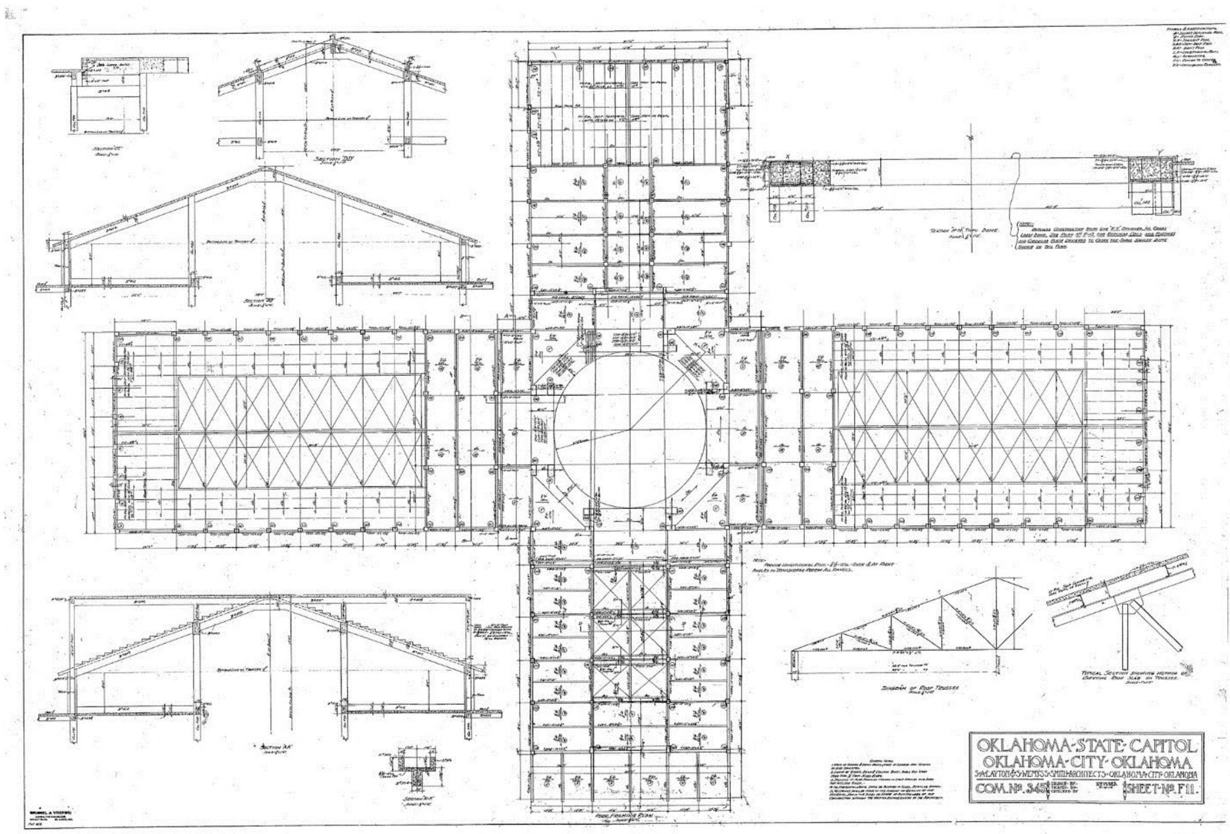


Figure 92. Sheet 11 of the original drawings shows the relationship of the gable columns with the masonry gable wall.

Figure 93. View of the Oklahoma State Capitol from the south

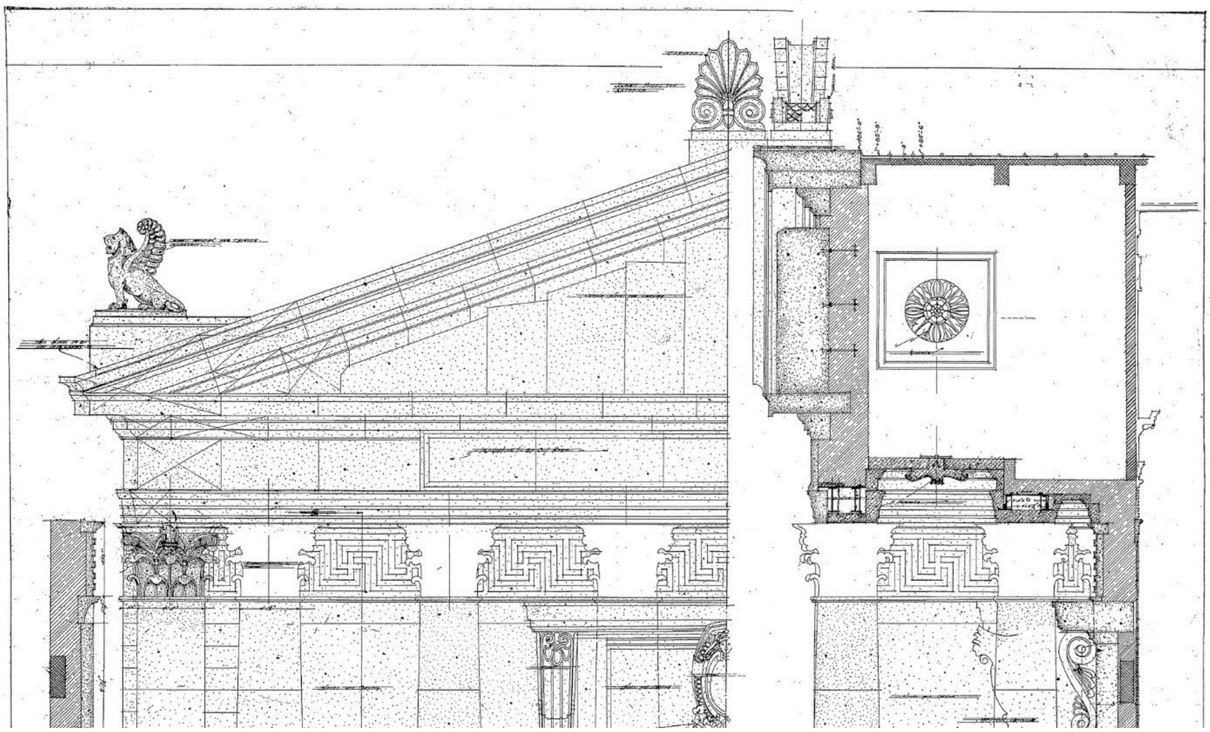


Figure 94. Close-up view of the south gable section as shown on sheet 14 of the original drawings

Figure 95. View of the back side of the south gable showing wire cable ties to concrete structure

Figure 96. Typical tieback of the wire cables to the concrete frame

Figure 97. Metal straps that engage two levels of projecting stone work on the exterior of the south gable

Figure 98. Crack in the corbel at reinforced concrete beam

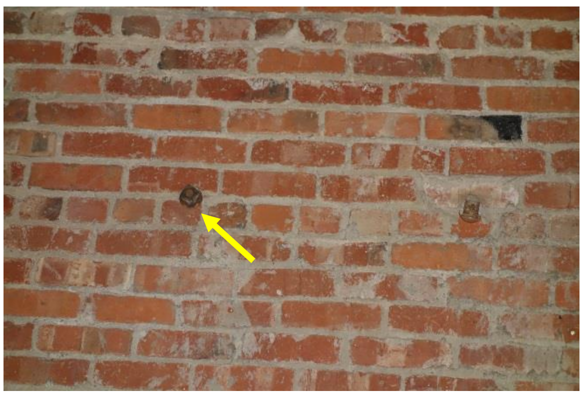


Figure 99. Through-bolt anchors present on the inside of the south gable wall

Figure 100. Heavy steel framing on the floor of the south attic between the concrete frame and masonry wall supporting the south portico soffit

Figure 101. The stone ceiling of the south portico (above)

Figure 102. The metal straps that engage projecting limestone on the exterior of the west gable (right)

Figure 103. Another view of the metal straps on the west gable wall (above)

Figure 104. The masonry wall is constructed outboard of the concrete frame by 4 inches (right).

Figure 105. Crack between the brick wall and concrete frame at west gable

Figure 106. The gypsum panels above the House chamber are cracked.

Figure 107. The metal straps that engage two levels of projecting stone work on the exterior of the north gable (above)

Figure 108. The east gable wall is finished with rough plaster, unlike the interior walls of the other gables (right)

Figure 109. Metal anchors that connect the masonry of the east gable to the concrete frame

Exterior Doors and Windows

The project manual specifies the south portico main and side doors as cast iron and all exterior doors to be glazed with plate glass. The window sills, pilasters, mullions, cornices, transom bars, etc., are also specified as cast iron. The window frames are specified as "heavy rolled steel" sections. The corners of the frames are to be welded.

The upper and lower sash of the double-hung windows are specified to be "open hearth" steel and counterweighted. The sash jambs are to be "cold drawn." The corners of the sash are to be welded. The sash are to be "sherardized," a form of galvanizing, prior to painting.

A heavy brass jamb section is specified so that the sash can be installed after the "rough trades are out of the building," which indicates that the window frames were to be installed during the masonry work, and the sash were to be installed with the finish trades work (such as plastering and flooring installation). It is specified that the cast iron and steel frames are to be shipped separately from the sash. Glazing was to be "Crystal glass," a low-iron glass that is clearer than regular glass. The sash were specified to be removable for maintenance purposes, and the counterweights were also to be easily accessible.

According to the original drawings, decorative features such as columns and spandrels and non-decorative features such as larger mullions are identified as cast iron. The remainder of the members such as frames and sills are designated as "metallic" without specifying the metal (Figure 110).

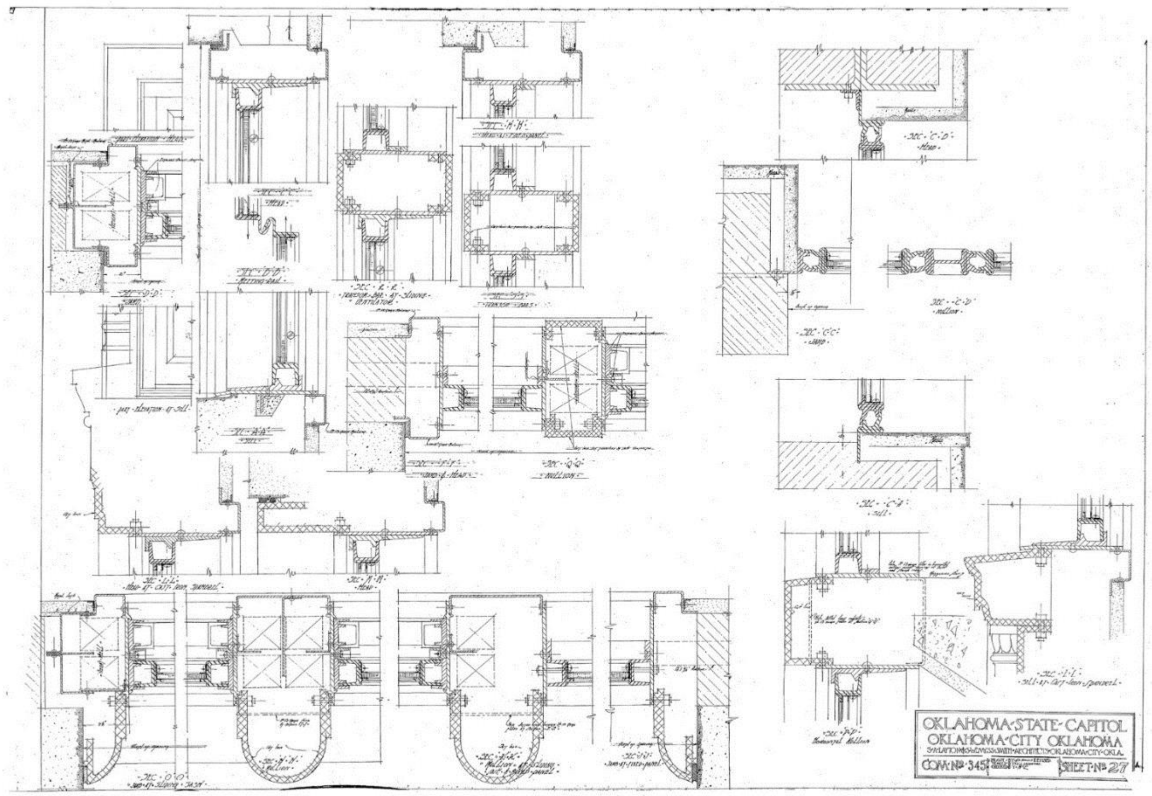


Figure 110. Window details from Sheet 27 of the original architectural drawings

Visual Inspection

The windows were visually inspected from grade, from a personnel lift at the south facade of the east wing and the east facade of the east wing, from disassembly of previously patches (south wing west side second floor), and from disassembling windows in the snack bar (north wing east facade, fourth floor). We noted the following during this visual inspection:

1. The materials for the decorative work, window frames, and window sash appear to be generally constructed in accordance with the drawings and specifications.
2. Broken glass exists at various windows (Figure 111 and Figure 112).
3. The window frames are painted with multiple layers of paint (described in further detail below).
4. The existing coatings have areas of peeling and blistering, and surface corrosion exists on the underlying metal.
5. Interior hardware, such as operating handles and locks, has typically been removed and painted shut (Figure 113).
6. Many of the original windows have applied interior aluminum storm windows. The storm window frame profile and center horizontal rail generally match the profile of the original sash and meeting stile (Figure 114).
7. The window sash are interior wet-glazed with U-shaped break metal steel glazing beads that have been screwed in place. In places where the windows have been reglazed, new screws have been installed.

Figure 111. Broken glass

Figure 112. Broken glass

Figure 113. Typical interior condition of the double-hung windows (above)

Figure 114. A window with an interior fixed storm window applied (right) and suspended ceiling blocking access to the upper sash

Window Removal

One window was removed from the interior at the south facade of the east wing at the fifth floor. The goal of the removal was to remove one set of sash and one frame while leaving all of the cast iron work in place. As the window chosen had an interior storm window, the interior storm was reinstalled in place of the removed window on a temporary basis. The following was observed during the window removal process:

1. The interior storm windows, where they have been installed, have caused damage due to the capture of condensation between the windows and consequent corrosion of the original window frames and sash at the sill (Figure 115).
2. The sash are not easily removed due to corrosion of the parting stops and fasteners (Figure 116).
3. The counterweights do not come out easily (Figure 117).

4. Cast iron, rolled steel, break metal steel, and brass components are found in the window systems as specified (Figure 118).
5. The rolled steel sash (Figure 119) and break metal steel sill (Figure 120 through Figure 122) have been repaired with a metal repair putty (filler). The filler was easily removed and not well bonded to the original steel.
6. The steel frames can easily detach from the cast iron but are laid into the surrounding masonry, making the removal of the frames impossible without cutting the frame.
7. The plaster end bead is attached directly to window frame on the interior so some plaster removal is required to remove the window frame (Figure 123).

Figure 115. Advanced deterioration and corrosion of the original lower sash and the frame sill (above)

Figure 116. Removal of the upper sash still connected to the counterweight chain (right)

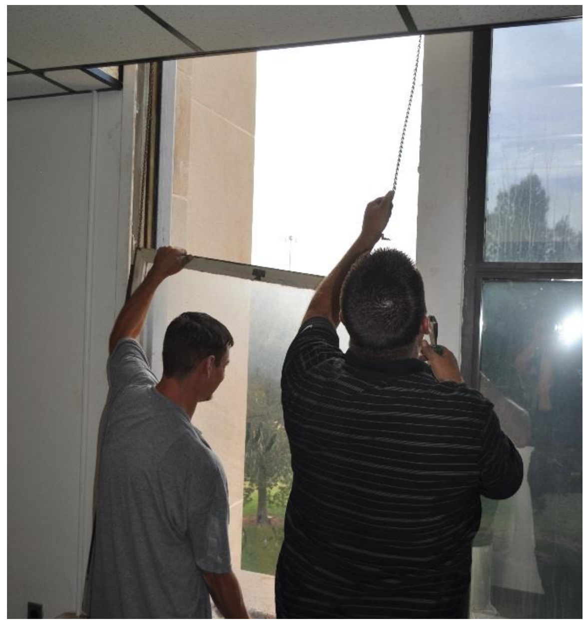


Figure 117. Sash counterweights made of pig iron

Figure 118. Section cut at the steel sill

Figure 119. View of the bottom portion of the lower sash

Figure 120. A portion of the corroded break metal steel sill

Figure 121. Corrosion of mullion between window sash

Figure 122. View within the mullion between the two windows

Figure 123. Close-up view of the left sill

Coatings

The original documents indicate that the metal sash, exterior doors, and cast iron were to be coated with three coats of paint and that the finish color shall match statuary bronze.

The window sash, frames, doors, and spandrels are ferrous metal, a combination of steel and cast iron, all are coated with a gray-colored coating (Figure 124 through Figure 126). Typically, the coating is moderately chalked with isolated peeling paint. The base metal exhibits some isolated spot surface corrosion (Figure 127). Dry Coating thickness was measured by magnetic gauge per ASTM D7091, *Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals*. The results are summarized in Table 3.

Table 3. Dry Film Thickness - D7091

Test	Location	Total (mils)
1	Third Floor Spandrel	8.7
	Third Floor Spandrel	10.5
	Third Floor Spandrel	7.3
2	Third Floor Window Sash	6.9
	Third Floor Window Sash	14.0
4	Second Floor Window Mullion	21.3
5	Second Floor Window Sash	9.3

Figure 124. Typical coating at window framing

Figure 125. Typical door coating

Figure 126. Typical view of coating at window and spandrel (left)

Figure 127. Close-up view of surface corrosion at coated spandrel (above)

Laboratory Analysis

Select samples of the coatings were removed from the cast iron and steel elements to identify the earliest extant paint color. Initially, the unmounted samples were viewed with a stereomicroscope under 10x to 63x magnification. Selected samples were prepared for more detailed microscopic visual analysis. Preparation of the samples included mounting them in a resin and polishing the samples cross section with successively finer grades of abrasives. The prepared cross-sectioned samples were analyzed with reflected light supplied by a quartz halogen light source equipped with a daylight-balanced filter under magnification ranging from 10x to 63x. The light source used was in compliance with ASTM D1729, *Standard Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials*.

Significant and representative finishes layers were given a Munsell color number.[1] The Munsell color number that most characteristic of the sample was chosen. Color matching was done in accordance with ASTM D1535, *Standard Practice for Specifying Color by the Munsell System*. The results are summarized in Table 4.

Table 4. Finishes Samples

Sample	Sample Location	Polished section
1	West facade of south wing, third floor, cast iron spandrel background	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
2	West facade of south wing, third floor, cast iron spandrel background	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
3	West facade of south wing, third floor, cast iron spandrel ornament	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
4	West facade of south wing, third floor, cast iron spandrel ornament	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
5	West facade of south wing, third floor, cast iron spandrel half-moon	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)

[1] The Munsell color system is a scientific alpha-numeric based system used to describe colors.

Sample	Sample Location	Polished section
6	West facade of south wing, third floor, cast iron spandrel half-moon	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
7	East facade third floor, spandrel background	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
8	East facade third floor, spandrel background	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
9	East facade third floor, spandrel center vertical	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
10	East facade third floor, spandrel center vertical	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
11	East facade third floor, window frame	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
12	East facade third floor, window frame	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)
13	East facade third floor, window sash	Very dark brown Dark green Dark gray or black White White Gray (currently exposed)

Sample	Sample Location	Polished section
14	East facade third floor, window sash	Black Dark green Dark gray or black White White Gray (currently exposed)

All of the polished sections reviewed included the same layer history or stratigraphy (Figure 128 through Figure 130). The samples consist of a gray layer, which is the currently exposed layer. The gray is applied over two layers of white, black or dark gray, dark green, and very dark brown at the base of the sample. Since the substrate is metal, no portion of the substrate was removed with the paint coatings; however, visual observations in the field confirm that the earliest extant coating is a very dark brown, consistent with the original specifications, which specified a statuary bronze color. The green layer in all samples is characteristic of Munsell 2.5GB 2/4. It is unknown when the dark green layer was applied or how long it was exposed prior to being covered by the dark gray/black layer. Based on the appearance of the building, and the colors in the stratigraphy, it is likely that the white layers are a primer.

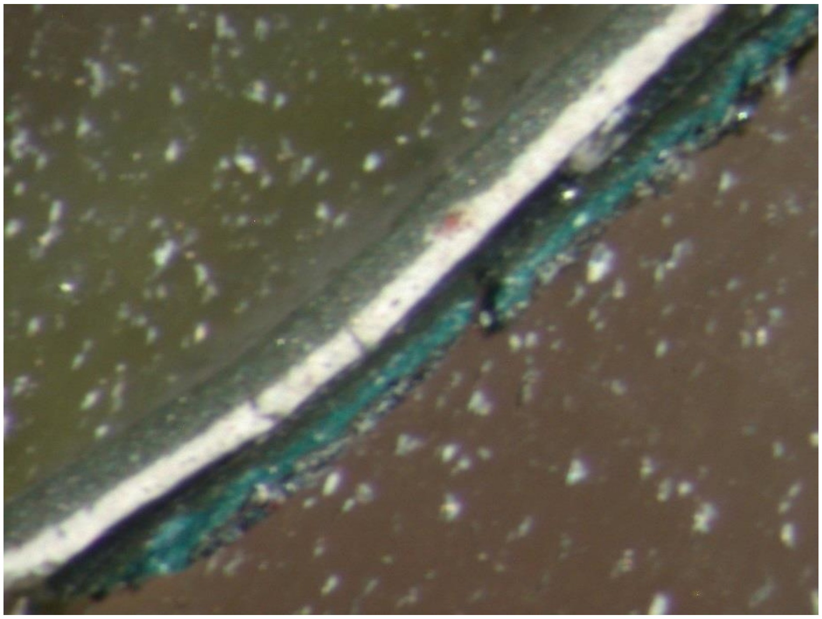


Figure 128. Section through Sample 1. The currently exposed gray layer is at the top left of the photo.

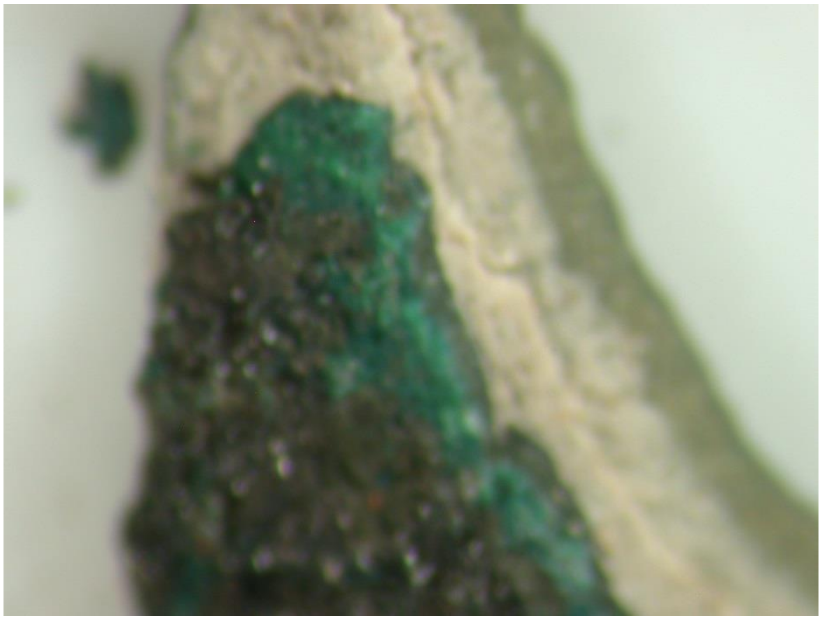


Figure 129. Unmounted fragment from Sample 3. Currently exposed gray layer is at the right of the photo.

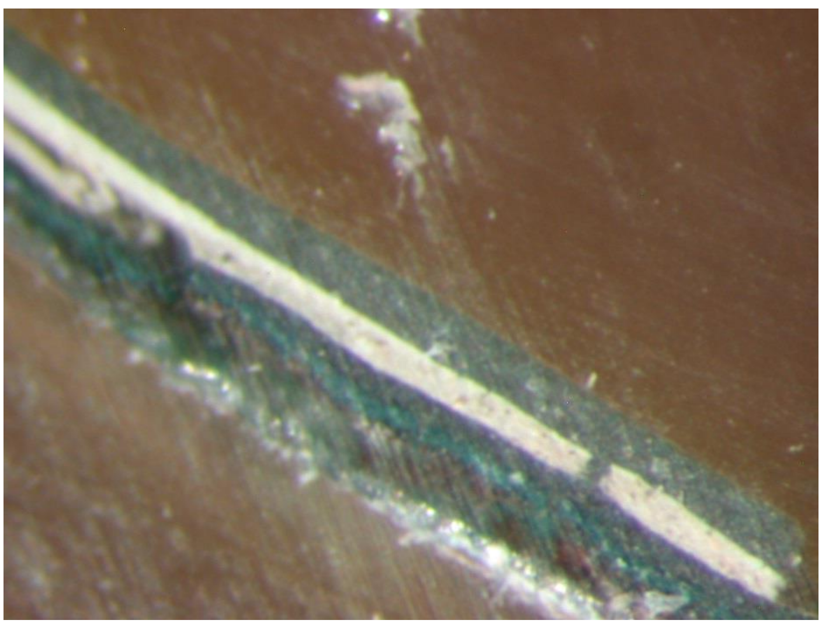


Figure 130. Section through Sample 7. Currently exposed gray layer is at the right of the photo.

Rotunda and Dome

The design-build work to complete the dome began in 2000, and the dome was completed in 2002. The dome framing consists of a combination of wide-flange steel beams and columns and cold-rolled steel framing with cast-in-place concrete slabs and cast stone cladding. Windows frames are thermally broken aluminum with insulating glass (IG) units. The cast stone units are reportedly set in a full bed of mortar and have vertical joints that are also filled with mortar with the outer 1/2 inch of horizontal and vertical joints sealed with silicone sealant.

Cast Stone

1. Cracking exists in cast stone units on the dome. Cracks exist at a total of 172 units, or approximately 10 percent of all cast stone units on the dome. Most of the cracks occur at the base of the dome. Some units have a single vertical crack located near the center of the unit (Figure 131), and other units have two or three parallel cracks through the same unit (Figure 132).
2. With assistance from a masonry contractor, a 3 inch diameter core was made through a vertical crack at one location near the northwest corner of the dome platform, and it was determined that the crack continues through the full thickness of the cast stone unit (Figure 133 and Figure 134).
3. Of the cast stone units that are cracked, approximately 10 percent of the units have craze cracking at the outside face of the unit (Figure 135). No cores were taken at units with craze cracking.
4. We did not examine shop drawings as part of our investigation. However, based on conditions observed at the core location and with a metal detector at five or six cast units, the cast stone is believed to be reinforced with mild steel (uncoated) horizontal bars.

Figure 131. Crack at cast stone near center of dome base unit

Figure 132. Parallel cracks within dome base cast stone unit

Figure 133. Overall view of core removed from cast stone crack location

Figure 134. Close-up view of cast stone core removed from cast stone crack location

Figure 135. Craze cracking at face of cast stone unit at base of dome

Inspection Openings

Inspection openings were made at various facade areas with the assistance of local masonry repair contractor to evaluate concealed conditions to determine potential cause(s) of distress. Openings were also made at other areas of the facade to evaluate similarly constructed facade area where there were no externally visible signs of distress. The inspection openings were temporarily repaired with in-kind materials to reduce the potential for water intrusion through the exterior wall at each opening location.

Conditions observed at the inspection openings are summarized below. A detailed description of findings at each inspection opening is presented in Appendix A.

Concealed Mild Steel

Limestone was removed to evaluate concealed conditions at the following locations with mild steel:

- Strap anchors at limestone frieze panels
- Strap anchors at limestone parapet wall panels
- Strap anchors at limestone spandrel between second and third floors
- Strap anchor at limestone ashlar adjacent to pilaster

- Lintels above clerestory windows in the House/Senate chambers
- Anchor rod for limestone cornice units

Strap Anchors

Inspection openings were made at a total of nine strap anchors locations. Of the nine strap anchors we inspected, six were at locations with no externally visible signs of distress, and three were at locations where the limestone had spalled. Of the six locations with no signs of distress, measurable corrosion scale was present at two locations, minor surface corrosion was present at two other locations, and only after limestone was removed, we determined that strap anchors were not originally installed at the remaining two locations.

Lintels

Inspection openings were made two lintels, one each above a clerestory window for the House and Senate chambers. A spall was present at the brick masonry for the opening above the Senate window, and no signs of distress were present above the House window. Both lintels consist of mild steel wide-flange sections with a 6 inch deep web and 3-1/4 inch wide flange. Both lintels 8 to 9 inches of bearing on the brick masonry pier adjacent to the window opening, but the brick masonry directly above the window had only 1 inch of bearing on the bottom flange of the lintel. Corrosion scale accumulation was present on the concealed surfaces of both steel lintels.

Cornice Anchors

Inspection openings were made at three locations where steel rods are set within the back face of the parapet wall and support the limestone cornice. Each rod is 1-1/8 inch diameter and is located approximately 4 inches from the back face of the brick masonry parapet wall. Of the three inspection opening locations, spalls were present in the limestone at two locations, and the back face of the cornice at the third location had been previously repaired with a limestone dutchman. Corrosion scale accumulation was present at each of the spalled locations and surface corrosion was present on the steel rod adjacent to the limestone dutchman.

Brick Masonry Piers

Three inspection openings were made to assess the connectivity between the limestone parapet brick masonry backup and the adjacent pier.

At each location, corrugated galvanized metal ties were present in the wall between the wythes of brick masonry backup. The ties were installed between wythes of brick and also between consecutive courses; in other words, the tie was bent in the shape of an elongated "Z" to engage brick masonry between inner and outer wythes of brick. Some minor corrosion exists on the surface of ties exposed at the openings.

The masonry piers at the back face of the limestone parapet coincide with exterior building columns (approximately 13 foot centers) and are each 2 feet 3 inches wide. The outer wythe of brick masonry for each brick pier is typically tied to the outer wythe of backup in the parapet wall; however, at two of the three openings, the brick within the pier was loosely placed as infill and not well tied to the parapet wall backup.

DISCUSSION

Facades

Corrosion-Related Distress

The majority of distress conditions observed at the Capitol are common for a building of this vintage. The original construction incorporated the use of varying thickness of limestone for lateral stability and mild steel strap anchors. The fact that mild steel shelf angles were not used to support limestone cladding has resulted in less corrosion-related distress than is common for limestone facades of this vintage.

Corrosion is the gradual loss of metal solids due to electrochemical reactions. The process is the reversion of the metal from its unnatural refined state to its natural ore, such as iron oxide or copper sulfate. In the presence of oxygen and water, which act as an electrolyte, the flow of electrons or charged ions causes corrosion to occur at the anode, while reduction occurs at the cathode. The rate of corrosion is dependent on several factors including the composition of the metal as well as humidity, temperature, water pH, and exposure to pollution and salts.

The rate of corrosion when the pH of a material is between 4 and 10 is essentially constant and relatively low. When the pH falls below 4, the rate of corrosion accelerates dramatically. In masonry wall systems, mortar and cement materials initially create an alkaline environment with a pH of approximately 10. As carbon dioxide from the environment penetrates the mortar and causes carbonation, the pH is reduced, resulting in increased corrosion.

Atmospheric corrosion is the corrosion mechanism that generally has the greatest impact on masonry construction. Unprotected ferrous metal exposed to the environment in the presence of moisture results in corrosion potential between two points on the surface of the metal. Variability of corrosion will occur with differing electrical potentials on a wet metal surface, possibly due to variations in the composition of the metal. Corrosion is most rapid when water covers only a part of the surface and will occur at the interface between the wet and dry areas.

Generally, the corrosion process of metal components within a masonry wall system can be divided into three phases. Phase one includes the first 30 years of service life of the building and represents the period of time when the underlying steel is protected by the alkalinity of the environment and various corrosion inhibiting coatings that may have been applied to the steel. In phase two, as the protective systems deteriorate, the steel begins to corrode as it is exposed to water and oxygen. Corrosion begins and continues when the moisture content of the masonry exceeds 2 percent by weight. This initiation of corrosion often begins within the first 60 years of service life of a building. In phase three, the corrosion progresses to the point of visible deterioration, and causes distress such as cracking and displaced masonry. The distress is the result of the accumulation of corrosion scale, which occupies a volume between four and twelve times the original volume of the uncorroded metal. Therefore, significant distress will result as the cladding system attempts to accommodate the accumulating scale.

Over time, the corrosion of embedded steel straps will result in the development of additional distress, including spalls and cracks, which is generally consistent with the distress observed during this investigation. Although it is difficult to assess the timeframe in which corrosion of the steel strap anchors may become a widespread issue, the presence of corrosion at inspection opening locations indicates that corrosion development has already begun. This is not unexpected since the steel is only protected by a lead-based primer and the original mortar has likely completely carbonated, resulting in loss of the passivating protection provided by new, uncarbonated mortar. Since it is not realistic or practical to address all of the existing steel strap anchors in the building, regular maintenance and repairs should be anticipated. Maintaining the joints between limestone units is important in reducing the rate at which future distress will develop. To minimize current disruption to historic exterior fabric that is otherwise presently intact, repairs and maintenance to address corrosion of limestone strap anchors may involve a combination of dutchman repairs, removal and reinstallation or replacement of limestone panels, and ongoing maintenance and inspection of the facade to identify and repair future distress before it becomes a hazard.

Movement-Related Distress

Vertical cracks observed in the limestone and granite panels near outside and re-entrant building corners are likely due to the inability of the wall construction to accommodate thermal movement and differential movement between the cladding, brick masonry backup, and reinforced concrete building frame. The lack of expansion joints in the wall cladding is consistent with construction standards at the time this building was built. Brickwork typically expands during the first few years after construction due to the absorption of moisture. Over time, the cladding and brick backup also expands and contracts regularly due to thermal changes. Since these movements are not accommodated in this wall, the buildup of stresses in the exterior wall is relieved with the development of cracks in the cladding. The cracks typically occur at the corners, since the intersecting wall restrains the buildup of forces within the length of the wall. In some cases, the incipient spalls at third floor limestone windowsills and cracks that exist in vertical mortar joints between limestone pilasters and adjacent limestone ashlars along the length of the wall may also be relieving stress within the wall. The cracks in vertical mortar joints allow moisture to enter the wall system. Water that enters cracked mortar joints accelerates corrosion of strap anchors between the pilasters and adjacent ashlars and in a few instances has led to cracks and spalls in the limestone units.

Lateral Support

Limestone Ashlars

Portions of the limestone cladding are keyed into the brick masonry backup and concrete building frame, while other areas have limestone panels that are constructed of a uniform thickness and have mild steel strap anchors set into the brick masonry backup. The strap anchors were very likely used as a means by which to set the limestone into place and maintain alignment with adjacent panels while upper levels of cladding and backup were being constructed. For limestone panels that are not keyed in to the brick backup or concrete frame, the straps provide long-term lateral support.

Parapet Walls

More severe deterioration would be expected to occur at the parapet since it is exposed to weather on each face of the wall; the back face of the wall is not heated (as is the case with typical exterior wall areas below the roof level), and, prior to the application of paint to brick on the back face of the wall, the wall was susceptible to increased water penetration through mortar joints between brick units. Historically, the upward-facing joints lead to water intrusion and freeze-thaw damage, though there is little evidence of freeze-thaw damage to the brick backup within the parapet wall. Previous treatments (sealant in upward-facing joints and paint at the back face of the parapet wall) have possibly mitigated long-term damage to the lateral stability of the parapet wall. The use of paint on brick masonry, however, is a poor long-term solution to mitigate water and maintain stability of exposed brick masonry structures.

The metal detector survey and inspection openings in the parapet show that strap anchors exist in less than 5 percent of parapet ashlars on the north and south facades. The relatively low number of parapet wall panels that are anchored with mild steel strap anchors have spalled. Lateral stability, therefore, is established only by mortar bond between the back face and edges of the limestone and surrounding construction including copings and brick masonry backup.

The absence of mild steel strap anchors for the limestone parapet ashlars indicates that these panels are relying on mortar bond only for lateral support. The limestone parapet panels are bonded to the brick masonry backup with a collar joint, and the mortar at head (vertical) and bed (horizontal) joints provides shear resistance between vertically adjacent panels. Aside from the bond loss of mortar at the outside face of the panels, there is little evidence that the mortar within the collar is joint is in poor condition. Nonetheless, it is our opinion that lateral support for the parapet wall panels should include mechanical anchorage to the brick masonry backup via stainless steel straps or ties.

Attics

The Capitol is considered an early use of reinforced concrete framing on a large scale. If the gables had been constructed within the concrete frame they would be expected to become well-connected over time due to the natural moisture expansion of the clay masonry and the natural shrinkage and creep of the concrete frame. These opposing forces would lock these two assemblies together.

However, the west, north, and east gables were constructed outboard of the concrete frame, and consequently, there is a potential for lateral movement or separation to occur between the assemblies. At the west gable where the exterior masonry is outboard of the concrete frame by 4 inches, cracking exists that indicates a separation between the brick masonry and concrete frame. At the east gable, ties were introduced to the brick masonry and concrete frame interface that were not introduced at the west and north gables.

At the south gable, the exterior wall is freestanding of the concrete frame but is presumably tied to the concrete roof deck. As the gable was being constructed, it was stabilized on a temporary basis by wire cables that are still in place. One of the brick corbels is damaged where the concrete roof beam is set into the south gable wall. Therefore, there is an instability at the south gable that could be easily exacerbated during seismic activity.

Mortar

Mortar contributes to the overall integrity of a mass masonry wall and assists in preventing water infiltration. Selection of an appropriate mortar should be based on the masonry units, original mortar, and the existing conditions of the masonry assembly. A repointing mortar should typically be designed to have higher permeability and porosity than the adjacent masonry units and should typically be designed to match the appearance of the original mortar. Despite the presence of medium-gray mortar in the original pointing mortar specimen that we examined, the reference to non-staining cement in the original specification suggests that a white portland cement was originally used for the pointing mortar.

The coating on the mortar is mineral-based and is bonded to the adjacent limestone and repointing mortar. Chemical trials to remove the coating from the adjacent limestone in the field were unsuccessful.

Cleaning

The most gentle, effective cleaning method should be used, since gentle techniques are less likely to damage building components, accelerate future damage, and have unintended negative consequences. The gentleness of a chemical cleaning system should be based on its impact on the building materials, adjacent building materials, pedestrians and occupants, and the environment.

Improper cleaning can damage facade materials by causing staining or etching, discoloration, or more severe distress, such as corrosion of embedded anchorage. Damage such as surface etching can increase the likelihood and rate of future dirt accumulation, absorption of moisture, and surface deterioration. Cleaning can also present a potential source of damage to other building elements and materials such as windows, nearby structures, and the environment, as well as pose a hazard to workers and others in the work area. Special care is required in planning and implementing a cleaning program, especially on a public building where airborne chemicals may harm pedestrians.

Additional care must be used in selecting appropriate water pressure for rinsing of chemical cleaners from surfaces. Low-pressure water cleaning can be safely used to clean many (but not all) substrates; however, even plain water can damage a substrate if the pressure that it is applied with is too high.

Chemical cleaners require careful selection and application. Some chemical cleaners may be very hazardous to humans and animals regardless of their environmental effect or chemical description. Certain aggressive acids present in some proprietary cleaners, including hydrochloric and hydrofluoric acid, are of special concern because they are not only hazardous but they can significantly damage building materials. Some products marketed as “detergents” or as “environmentally friendly” actually contain aggressive acids or compounds that form aggressive acids when combined with water and should not be used for building cleaning. Aggressive chemicals can etch or dissolve the components of limestone and may cause severe staining and other damage. Cleaners with aggressive chemicals were not included in our trials based on our experience with these cleaners causing damage to building facades.

Exfoliation

The cause of the exfoliation in limestone units is not known at this time. Exfoliation can occur in sedimentary stones when the units are installed with the bedding planes oriented parallel to the face of the wall rather than perpendicular as they would occur naturally. “Face-bedded” material generally results in thicker portions of the stone shearing off from the parent stone over the entire face of a particular face-bedded unit. Face-bedded stone is more susceptible to severe weathering-related deterioration because separations develop between and at interfaces between beds. Thinner, partial area exfoliation, similar to that observed at the Capitol, is less likely to be the result of face-bedded limestone and more likely to be caused by other factors such as use of de-icing salts, rising damp, and surface treatments. Based on our close-up inspections, the limestone does not appear to be face-bedded.

It is likely, however, that a silicone-based penetrating sealer (silane or siloxane) applied to the exterior surface of the limestone walls as part of the 1980s repointing project has adversely affected the limestone and caused moisture to become trapped within the stone. In certain circumstances, water repellents and consolidants are used on stone in an attempt to minimize the rate of decay and to strengthen decayed stone where there has been a failure of the natural stone cement through the normal processes of weathering. However, where penetration depth is low (less than 1/4 inch), surface spalling, salt crystallization or frost damage below the treated layer can occur, resulting is shallow localized areas of delamination (exfoliation).

Parapet Coatings

The paint that exists on the exposed surfaces of brick masonry including the back face of parapet walls and adjacent to the clerestory windows for the House and Senate chambers is likely a past treatment that was implemented to address water migration through the mass masonry wall. Early traditional masonry barrier walls controlled water by absorbing water that penetrated the exposed surface and slowly dispersing it as water vapor. As exterior wall design evolved, cavity and curtain walls were designed to accommodate and control water that bypassed the outer surface and channel water to where it could be diverted back to the exterior by internal flashings and weep provisions. In the absence of significant reconstruction to change the behavior of the brick masonry wall areas, coating the exposed brick masonry surfaces was an inexpensive treatment designed to reduce water intrusion through brick masonry facade areas and reduce interior water leaks.

Windows

Corrosion of the steel-framed windows on the main facades is related to deterioration of protective exterior coatings and moisture migration through the exterior walls and subsequent corrosion development on concealed portions of the steel frame. Corrosion of the steel window frames is also the result of the lack of a thermal break between exposed interior and exterior metal surfaces, a condition that produces condensation on the frames.

Based on conditions observed during the window removal, it is apparent that the concealed portions of the window sash and frames are in much worse condition than they appear, and there are no good options for the repair of steel windows with thin sheet steel components that will solve the performance and condensation issues. It is also apparent that the present windows will never be made operable again. The best option to improve thermal performance of the existing windows is the addition of storm windows. However, storm windows have been previously installed and resulted in damage to the original window frames.

The plaster end bead is attached directly to window frame on the interior, so some plaster removal is required to remove the windows. Interior finishes (ceilings, cabinetry, and furniture) are typically in the way of the interior window access. These obstacles will need to be addressed in a window repair or replacement program.

Steel Coatings

The coatings protect the cast iron and steel elements against corrosion. The coatings are at the end of their service life and should be replaced. Compete removal of the coatings and surface preparation by abrasive blasting will permit the installation of the highest-performing coating system in terms of corrosion resistance. The metal components should be painted to match their historic appearance. Removal of the existing coatings likely will require abatement of hazardous materials. Analysis for hazardous materials was beyond the scope of our study.

CONCLUSION

Distress observed in the exterior walls of the Capitol including spalls and cracking is the result of the corrosion of embedded steel anchors (straps and rods) and unaccommodated and differential movement between the limestone cladding, brick masonry backup, and the concrete building frame. Other distress conditions, such as bond separation of mortar, exfoliation of limestone, and staining on the facade is the result of a combination of unsuccessful previous exterior wall treatments and natural weathering.

Based on our review of original drawings, visual survey, and conditions observed at intrusive openings in the exterior wall, it is anticipated that spalls and cracks will continue to develop in the vicinity of original mild steel cladding support elements as a result of normal exposure to weather conditions. The rate at which new facade distress will develop cannot be predicted. Therefore, the recommended treatments should address removal of and replacement of selected original mild steel strap anchors with stainless steel strap anchors, movement accommodation, water intrusion, and selective repair or replacement of original exterior wall fabric.

Corrosion of the steel-framed windows and cast iron elements on the main facades is related to deterioration of exterior coatings and moisture migration through the exterior walls and subsequent corrosion of concealed portions of the steel frame. Another contributing factor of the corrosion of the steel window frames is the lack of a thermal break between the interior and exterior metal surfaces, a condition that produces condensation on the frames.

RECOMMENDATIONS

The recommendations outlined below are based on the conditions observed during our investigation, expected rate of continued deterioration and appropriate repair and restoration approaches given the historical significance of the building.

The repairs described below are not prioritized, as it is our understanding that the exterior walls of the building are to be addressed as part of a comprehensive repair, renovation, and restoration project for the entire building. Therefore, recommended exterior wall repairs are all considered to be equally important in addressing both critical repair issues and other conditions to minimize the potential for development of future distress. The repairs also consider aesthetic impact and exterior wall maintenance issues.

Based on our review of original documents, conditions observed during our investigation, and field and laboratory studies, long-term repairs should consist of the following.

Limestone and Granite

- Spalled limestone units should be replaced with new limestone to match the original panel size and thickness. For unusually large or thick panels, spalled areas may be repaired by installing limestone dutchman units.
- Cracked panels (limestone and granite) should be dealt with on a case-by-case basis.
  - Limestone panels with cracks that are wider than 1/16 inch should be removed and replaced with new limestone to match the original panel size and thickness. For unusually large or thick limestone or granite panels, cracks may be repaired by grinding the crack to a depth of 3/4 inch and installing backer rod and sealant. In some instances, supplemental stainless steel reinforcement should be installed to stabilize the cracked unit.
  - Panels with cracks that are between 1/16 inch wide and 0.010 inch wide should be ground out and backer rod and sealant installed.
  - Hairline cracks that are less than 0.010 inch wide may be left untreated.
- For limestone panels where significant exfoliation exists, the limestone unit should be replaced with new limestone to match the original panel size and thickness. Limestone units with surficial exfoliation may remain in service and be addressed by removing loose material.
- Displaced limestone should be evaluated further and be dealt with on a case-by-case basis.
  - Panels with cracks that are determined to be unsound should be pinned in place or removed and reinstalled or replaced.
  - Panels that are sound and intact may be left untreated provided that they are inspected as part of an ongoing maintenance program.
- Cracked or spalled limestone dutchman units should be removed and replaced. Existing dutchman units that are sound and intact need not be addressed and may remain in place indefinitely, provided that they are inspected regularly as part of an ongoing maintenance program.

- Iron inclusions are naturally occurring and generally do not adversely impact the performance of the stone and therefore need not be addressed.
- Naturally occurring seams, whether they are filled or open, need not be addressed. Special attention should be paid to differentiate between cracks and seams in limestone panels.

The limestone repairs should include further investigation with regard to identifying locations and evaluating the condition of original mild steel strap anchors, particularly at the limestone frieze. Repairs, if any, should be based on the findings of additional investigation.

Mortar

Bond failure and mortar wash-out is pervasive throughout the entire building. The original mortar is consistent with the original project specifications and consists of portland cement, sand, and lime. The building was repointed in the 1980s, and that work included application of a cementitious coating at the outside surface of the joint. In many instances, the coating extends on to the surface of the adjacent limestone by as much as 1/4 inch. All existing mortar on the exterior walls of the building should be ground to a minimum depth of 1-1/2 inches and pointed. Based on the analysis and field conditions, a Type N mortar by proportions is recommended for repointing the masonry wall. While no areas of original pointing were observed, based on the historic documentation, the original mortar used white portland cement and with a white sand aggregate. The repointing mortar should also use white portland cement and a white quartz aggregate to likely match the original appearance.

We recommend that a trial repair be performed on the exterior wall of the building to evaluate if mortar bond will be a concern based on the previous application of a water repellent and workmanship for future repairs. To accommodate anticipated thermal movement of the exterior cladding, we anticipate that selected vertical joints in the exterior wall will need to be addressed by grinding joints continuously for the full height of the building and installing backer rod and sealant.

The coating on the mortar bonded to the adjacent limestone and repointing mortar. The coating on the mortar joint will be removed during repointing. The coating on the adjacent limestone will be difficult to remove without causing damage to the limestone. Isolated mechanical removal may be successful using hand tools based on our field trials. However, considering the potential damage to original limestone, we do not recommend removing the coating remnants that exist on the limestone adjacent to mortar joints at this time.

Staining

A penetrating sealer was applied to the exterior surface of the limestone walls as part of the 1980s repointing project. The penetrating sealer has caused mottled orange and brown stains to develop at various locations on the limestone exterior walls of the building, particularly above the granite base course and below the cornice. Field trials were unsuccessful at removing the orange and brown stains.

Dark staining at the upper levels of the limestone facade (parapet walls and dome platform) generally consist of biological growth. Field trials were moderately successful at removing some, but not all, of the stains. The tested biocides require several months to demonstrate their full effectiveness and as a result will likely become more effective over time. The field trials should therefore be re-evaluated in three to six months.

We anticipate at this time that the cleaning treatment will include the application of biocide, which is considered to be gentlest effective method for removing biological growth that minimizes long-term damage to the face of the limestone panels. The light atmospheric soiling on the surface below overhangs should be cleaned using a very low-pressure water mist.

Parapet Walls

Long-term repairs for limestone-clad brick masonry parapet walls should address each of the following identified deficiencies:

- Corrosion of existing concealed mild steel anchorages for the parapet wall ashlars and limestone cornice
- Connectivity between the existing limestone parapet wall panels and brick masonry backup
- Water intrusion through the back face of the brick masonry parapet wall
- Permeability: originally designed as a mass masonry wall, any treatment to limit water migration through the exterior wall should also allow the exterior wall to "breathe."

Legislative Chambers Clerestory

Existing loose-laid steel lintels above masonry openings for clerestory windows in the House and Senate chambers should be removed and replaced with non-corrosive or corrosion-resistant steel lintels.

Coatings

The steel and cast iron elements includes preparing the existing material in accordance with SSPC SP10 Near White Blast Cleaning and coated with a three coat system including an organic zinc-rich coating, an epoxy, and a fluoropolymer to provide the greatest corrosion protection and color and gloss retention.

Windows

The main facade window sash and frames should be removed and replaced with thermally broken operable aluminum double-hung windows while leaving the cast iron components in place to be repaired in situ. This operation would very likely be performed entirely from the interior and the original sash and frames will be destroyed in the process. The work will need to be coordinated with existing interior finishes, including cabinetry and plaster finishes, as the window frames have been laid into the masonry and therefore will need to be cut away. The frames must be removed so that new window sash and frames can match the original in profile.

The new windows should incorporate IG units with low emissivity (low-E) glass coating, thermal breaks, and should match the original window profiles as seen from exterior. There should be a galvanic separator between the aluminum and cast iron to prevent galvanic corrosion.

Concrete Light Well Walls

The exterior light well concrete walls should be rebuilt. A new waterproofing membrane should be applied to the outside face of the concrete wall and the inside face can be finished with tile to match the original finish. The balustrade can be removed and reinstalled with stainless steel anchorage. Given that the concrete sidewalk next to the light well wall will also have to be removed and replaced, consideration could also be given to replacing the granite balustrade as part of comprehensive landscaping improvements to the Capitol grounds.

Attics

Cracking of the south gable brick corbels should be investigated further. Repairs will likely include removal and replacement of the cracked brick corbels. Additional repairs, if any, should be based on further investigation.
Straps should be installed at the west gable for supplemental lateral support between the concrete frame and brick masonry. Similar connections should be introduced at the north, south, and east gables.

The condition of gypsum panels installed at the west wing skylights should be studied further to determine if long-term repairs are necessary. If the gypsum panels, or portions thereof, are cracked and loose or friable, temporary protection that consists of netting could be installed to reduce the potential for damage to the House chamber laylights from falling debris until long-term repairs can be performed.

Cast Stone

Cracks exist in cast stone units predominantly at the lowest (base) level of the dome. The observed distress is a combination of craze cracking that is likely limited to the outer surface of affected units and vertically oriented cracks at other units that are generally full height and full depth of the unit where they exist. Additional investigation is necessary to determine the cause of distress and recommend repairs.

CLOSING

We appreciate the opportunity to work with you on this historic and challenging project. We anticipate that questions may arise during your review of our recommended treatments to repair and restore the exterior walls of the Capitol, and we would welcome the opportunity to discuss these with you and OMES project team.

WJE ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

APPENDIX A

Inspection Openings

OKLAHOMA STATE CAPITOL
Appendix A - Inspection Openings

Inspection Opening No. 1

Southeast roof level: cornice anchor bolt

- Located in back face of brick masonry parapet below a spall in the back face of limestone cornice (Figure A1).
- Cornice anchor consists of 1-1/8 inch diameter mild steel rod; the rod aligns with the joint between cornice units. The rod is located approximately 4 inches from the back face of the wall (Figure A2) and falls within the collar joint between the innermost wythes of brick masonry.
- Corrosion scale accumulation estimated to be 1/16 inch thick exists on the surface of the rod directly adjacent to the limestone cornice (Figure A3).

Figure A1. Overall view of location of Inspection Opening No. 1

Figure A2. Cornice anchor rod

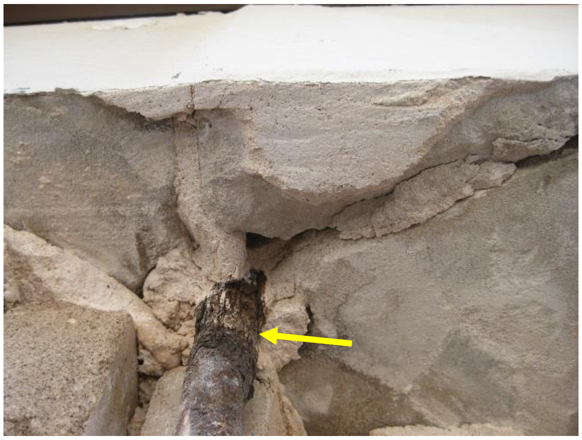


Figure A3. Corrosion scale on anchor rod

Inspection Opening No. 2

Southeast roof level: brick masonry pilaster

- Located in back face of the parapet adjacent to a brick masonry pilaster (Figure A4).
- Corrugated galvanized steel ties exist between the inner wythes of brick masonry (Figure A5). The ties are spaced 16 inches apart horizontally. Some minor corrosion exists on the surface of exposed ties. The ties engage less than one third of the brick unit.
- The wall is constructed with header units located at approximately 16 inch centers each way (horizontally and vertically).
- Header units do not exist between the pilaster and inner wythes of parapet wall
- Brick masonry within the pilaster is not integrally, reliably tied to back face of parapet wall (Figure A6).

Figure A4. Overall view of location of Inspection Opening No. 2

Figure A5. Galvanized ties within brick masonry

Figure A6. Lack of tie between pilaster and wall

Inspection Opening No. 3

Southeast roof level: steel lintel above clerestory window

- Located in brick masonry above steel-framed window toward east end of Senate chamber (Figure A7). The brick masonry was hollow-sounding and mortar joints between brick units are cracked.
- Lintel that supports masonry above the window consists of a loose-laid steel beam, 6 inch deep web and 3-1/4 inch wide flanges.
- The outer wythe of brick above the window has approximately 1 inch of brick bearing on the bottom flange of the steel lintel (Figure A8).
- Two square-headed bolts exist in the web of the steel lintel; the bolts do not engage anything on the inside face of the wall (Figure A9).
- Corrosion scale estimated to be 1/8 inch thick observed on the top face of the bottom flange.

Figure A7. Overall view of location of Inspection Opening No. 3

Figure A8. Bearing of brick on lintel below

Figure A9. Unengaged bolt at lintel

Inspection Opening No. 4

South facade parapet, east wing

- Located in the top edge of a limestone ashlar near the center of the east wing on the south facade. The location was selected to document the condition of the concealed mild steel strap anchor at a limestone panel with no visible signs of distress.
- No strap anchor exists at the inspection opening location (Figure A10 and Figure A11).
- Follow-up survey with metal detector indicates that the limestone parapet ashlars were constructed without strap anchors between the limestone and brick masonry back-up along the north and south facade of the east wing.

Figure A10. Lack of strap anchor within opening

Figure A11. Lack of strap anchor within opening

Inspection Opening No. 5

Southwest roof level: cornice anchor bolt

- Located in back face of brick masonry parapet below a dutchman in the back face of limestone cornice.
- The dutchman unit is approximately 3 inches thick, 1 foot 2 inches tall, and 3 feet 3 inches long (Figure A12).
- The cornice anchor consists of 1-1/8 inch diameter mild steel rod; rod aligns with joints between cornice units. The rod is located approximately 4 inches from the back face of the wall and falls within the collar joint between the inner-most wythes of brick masonry.
- Minor surface corrosion exists on the surface of the rod (Figure A13).
- Corrugated galvanized wall ties exist between the inner wythes of brick masonry in the parapet wall below the coping. No corrosion exists on the wall ties, which are spaced 16 inches apart horizontally. The ties engage less than one third of the brick unit at the back face of the wall (Figure A14).

Figure A12. Dutchman unit above inspection opening

Figure A13. Minor corrosion on cornice rod

Figure A14. Typical corrugated masonry tie

Inspection Opening No. 6

Southwest roof level: brick masonry pilaster

- Located in back face of parapet adjacent to brick masonry pilaster (Figure A15).
- The outer wythes of brick masonry are tied at alternating courses (Figure A16).
- No ties observed between brick header units between the pilaster and inner wythes of parapet wall. Header units are partially obscured by the coating (paint) on the back face of the parapet wall but appear to be spaced at 16 inch centers each way.

Figure A15. Location of Inspection Opening No. 6

Figure A16. Brick masonry header unit

Inspection Opening No. 7

South facade parapet, west wing

- Located in the top edge of a limestone ashlar near the center of the west wing on the south facade. The location was selected to document the condition of the concealed mild steel anchor at a limestone panel where a sealed crack was observed during our close-up inspection.
- A mild steel "cramp" anchor exists between adjacent limestone panels (Figure A17). No strap exists between the limestone panel and the brick masonry back-up.
- Surface corrosion exists on the surface of the cramp anchor (Figure A18). The limestone is cracked near the edges of the existing kerf.
- Spalls exist at the outside face of the limestone parapet wall on the south face of the west wing. Spalls only exist where there are cramps between adjacent panels.
- Based on our survey of the parapet wall using a metal detector, ties do not exist between the limestone and brick masonry back-up at locations that are not spalled.

Figure A17. Cramp anchor

Figure A18. Cracking at kerf within unit

Inspection Opening No. 8

South facade parapet, west wing

- Located in the top edge of a limestone ashlar near the center of the west wing on the south facade. The location was selected to document the condition of the concealed mild steel anchor at a limestone panel where a sealed crack was observed during our close-up inspection.
- A mild steel cramp anchor exists between adjacent limestone panels (Figure A19). No strap exists between the limestone panel and the brick masonry back-up.
- Corrosion scale on the surfaces of the anchor is estimated to be 1/8 thick.

Figure A19. Cramp anchor at crack location

Inspection Opening No. 9

Northwest roof level: cornice anchor bolt

- Located in back face of brick masonry parapet below a spall in the back face of limestone cornice (Figure A20).
- The cornice anchor consists of 1-1/8 inch diameter mild steel rod; rod aligns with joints between cornice units. The rod is located approximately 4 inches from the back face of the wall and falls within the collar joint between the inner-most wythes of brick masonry.
- Corrosion scale accumulation estimated to be 1/16 inch thick exists on the surface of the rod directly adjacent to the limestone cornice (Figure A21).

Figure A20. Overall view of location of Inspection Opening No. 9

Figure A21. Corrosion scale on surface of cornice rod

Inspection Opening No. 10

Northwest roof level: brick masonry pilaster

- Located in back face of the parapet adjacent to a brick masonry pilaster near the east end of the roof (Figure A22).
- The outer wythe of the pilaster is tied to the outer wythe of the parapet wall, however, brick masonry within the pilaster was loosely placed at the time of original construction and is not reliably tied to back face of parapet wall (Figure A23).

Figure A22. Overall view of location of Inspection Opening No. 10 (arrow)

Figure A23. Loose masonry within pilaster

Inspection Opening No. 11

Northwest roof level: steel lintel above clerestory window

- Located in brick masonry above steel-framed window toward east end of House chamber (Figure A24). The opening was made to assess concealed conditions at a location with no visible distress.
- Lintel that supports masonry above the window consists of a loose-laid steel beam, 6 inch deep web and 3-1/4 inch wide flanges. The bearing length for the lintel on the masonry pier at the east end of the window opening is estimated to be 9 inches.
- The outer wythe of brick above the window has less than 1 inch of brick bearing on the bottom flange of the steel lintel (Figure A25).
- Two square-headed bolts exist in the web of the steel lintel; the bolts do not engage anything on the inside face of the wall (Figure A26).
- Minor surface corrosion exists on the outside surfaces of the steel lintel.

Figure A24. Overall view of location of Inspection Opening No. 11

Figure A25. Bearing of brick on lintel

Figure A26. Unengaged bolt at lintel

Inspection Opening No. 12

North facade parapet, west wing

- Located in the top edge of a limestone ashlar near the east end of the west wing on the north facade. The location was selected to document the condition of the concealed mild steel anchor at a limestone panel where a mortar patch was observed during our close-up inspection.
- A mild steel cramp anchor exists between adjacent limestone panels (Figure A27). Surface corrosion exists on the anchor and the limestone is cracked at the back face of the limestone panel.
- No strap exists between the limestone panel and the brick masonry back-up.

Figure A27. Cramp anchor between limestone panels

Inspection Opening No. 13

North facade parapet, west wing

- Located in the top edge of a limestone ashlar near the east end of the west wing on the north facade. The location was selected to document the condition of the concealed mild steel strap anchor at a limestone panel with no visible signs of distress.
- No strap anchor exists at the inspection opening location (Figure A28).
- Follow-up survey with metal detector indicates that the limestone parapet ashlars were generally constructed without strap anchors between the limestone and brick masonry back-up along the north facade of the west wing.

Figure A28. Lack of anchor within opening

Inspection Opening No. 14

South facade, portico frieze

- Located in the top edge of a limestone ashlar near the west end of the frieze on the south portico. The location was selected to document the condition of the concealed mild steel anchor at a limestone panel where a spall was observed during our close-up inspection (Figure A29).
- A mild steel cramp exists between adjacent limestone panels. Corrosion scale accumulation estimated to be 1/4 inch thick exists on the surfaces of the anchor. The anchor is approximately 1/8 thick and 10 inches long (Figure A30).
- Strap anchors exist near the edge of each panel near the opening. The strap anchors are set in the brick masonry backup are located approximately 12 inches from the vertical joint between panels (Figure A31). Corrosion scale accumulation on each strap varies between 1/16 inch and 1/8 inch.
- The mortar joints in the cornice and pediment directly above the opening are washed out (Figure A32).

Figure A29. Overall view of location of Inspection Opening No. 14

Figure A30. Corrosion scale on strap anchor

Figure A31. Strap anchors set in brick masonry backup

Figure A32. Open mortar joints above inspection opening

Inspection Opening No. 15

South facade, pilaster jamb ashlar

- Located on the east face of the pilaster at the southwest corner of the building. The location was selected to document the condition of the concealed mild steel anchor at a limestone panel where a spall was observed during our close-up inspection (Figure A33).
- A mild steel cramp exists between the pilaster and adjacent “jamb” ashlar (Figure A34). The anchor is approximately 1/8 thick and estimated to be 10 inches long. Surface corrosion exists on the surface of the mild steel anchor.

Figure A33. Location of Inspection Opening No. 15

Figure A34. Anchor within jamb unit

Inspection Opening No. 16

South facade, spandrel below 3rd floor window

- Located in the limestone spandrel between the second and third floor, at the southwest corner of the building. The location was selected to document the condition of the concealed mild steel strap anchors at a limestone panel with no visible signs of distress (Figure A35).
- The spandrel consists of three limestone ashlars, each 12 inches high and 4 inches thick. The center panel is approximately 4 feet long and the two outer panels are each approximately 2 feet long.
- The center spandrel panel was removed to review concealed conditions. The limestone was installed with one strap anchor at the left (west) side of the panel (Figure A36). Very minor surface corrosion exists on the concealed strap anchor. A strap does not exist at the right (east) side of the panel (Figure A37).
- Remnants of sealant exist at the outside face of the horizontal mortar at the top of the panel.

Figure A35. Overall view of location of Inspection Opening No. 16

Figure A36. Strap anchor within opening

Figure A37. Lack of strap anchor within opening

Inspection Opening No. 17

South facade, portico frieze

- Located in the top edge of a limestone ashlar at the frieze on the south facade near the southwest corner of the building. The location was selected to document the condition of the concealed mild steel anchor at a limestone panel with no visible signs of distress.
- A mild steel cramp exists between adjacent limestone panels. Very minor surface corrosion exists on the surface of the cramp anchor and the original primer paint is visible on the surface of the mild steel anchor (Figure A38).
- A strap anchor exists near the edge of the panel near the opening. The strap anchor is set in the brick masonry back-up are located approximately 12 inches from the vertical joint between panels. Surface corrosion exists on the mild steel strap and the limestone is spalled to the back face of the panel.
- Remnants of sealant exist at the outside face of the horizontal mortar at the top of the panel.

Figure A38. Surface corrosion on cramp anchor

Figure A39. Photograph of south facade, east wing, showing locations of inspection openings. Inspection openings noted in red are on the back face of the facade.

Figure A40. Photograph of south facade, west wing, showing locations of inspection openings. Inspection openings noted in red are on the back face of the facade.

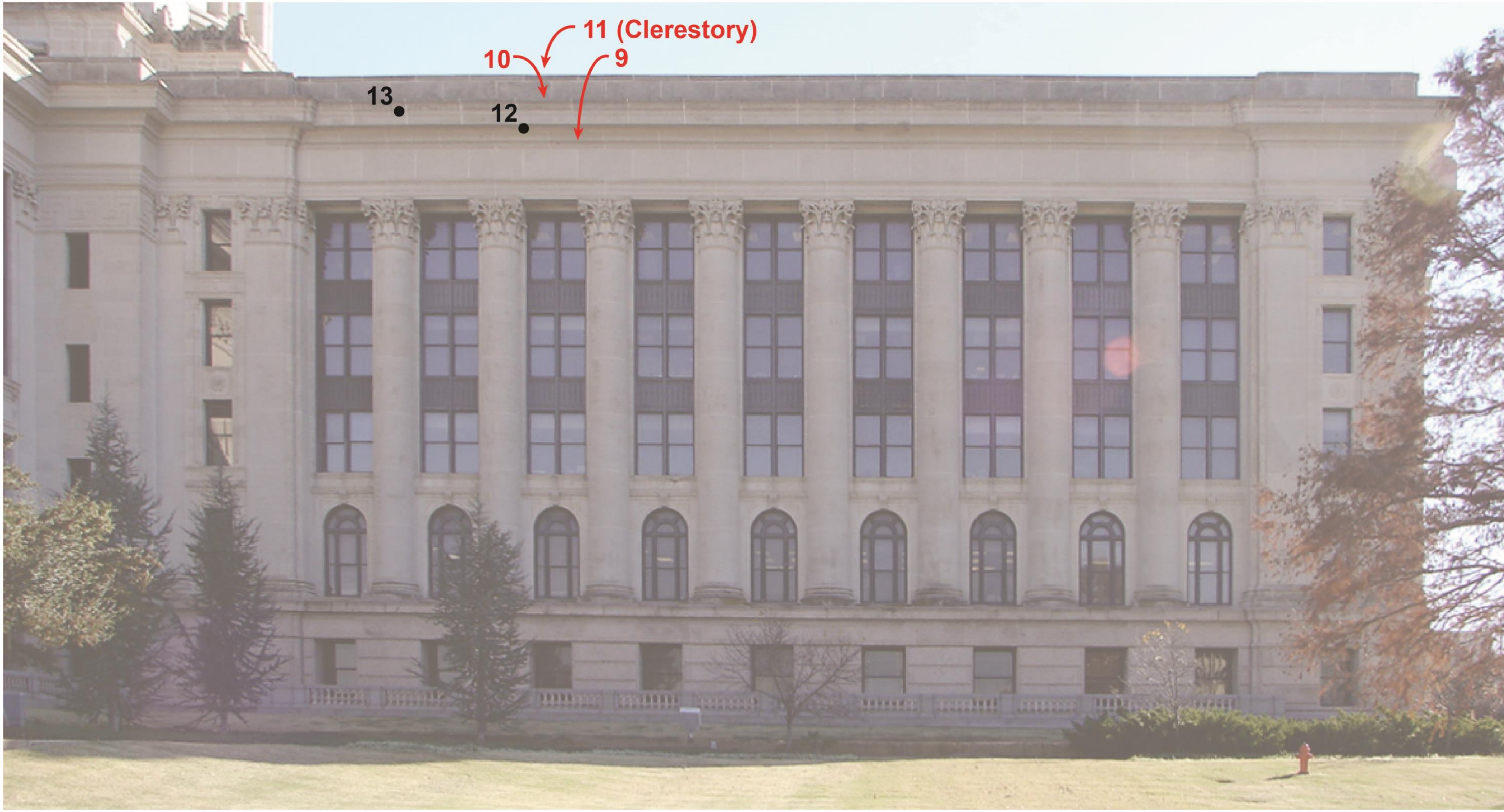


Figure A41. Photograph of north facade, east wing, showing locations of inspection openings. Inspection openings noted in red are on the back face of the facade.

Figure A42. Photograph of south facade showing locations of inspection openings