GRAEF ANHALT SCHLOEMER and Associates Inc.

ISTHMUS ARCHITECTURE, INC.

WISCONSIN STATE CAPITOL DOME MOISTURE STUDY

101 East Wilson Street, 7th Floor, Madison, Wisconsin

Structural Investigation Report

Final Report
October 13, 2008

Prepared for:
Wisconsin Department of Administration/Division of State Facilities
101 East Wilson Street
Madison, WI 53707

DSF Project No.: 03K3Q

Prepared by:
Graef Anhalt Schloemer & Associates, Inc.
5126 West Terrace Drive, Suite 111
Madison, WI 53718

In Association with:
Isthmus Architecture, Inc.
613 Williamson Street, Suite 203
Madison, WI 53703

GRAEF ANHALT SCHLOEMER and Associates Inc.

ISTHMUS ARCHITECTURE, INC.

TABLE OF CONTENTS

Table of Contents 2

Objective & Scope of Work 3

Observations and Findings 3
- Main Truss Bottom Pin Connections 3
- Granite Stone Connections 4
- 2-inch Cavity 7
- Gutter (located at the bottom of the dome in the interstitial space) 7
- Corrosion on Truss Members 8
- Compression Ring 9
- Plaster on the inside of the outer dome 10

Summary and Recommendations 13
- Previous Phase I work 13
- Findings of Structural Phase II investigation 13
- Factors Contributing to Moisture & Humidity Problems 14
- Recommendations and Conclusions 14

Costs 15

Appendix A: Dome Truss Location Diagram, dome section and outer dome truss section 16

Appendix B: Summary Report Dated January 15, 2008 19

Objectives & Scope of Work:

The objective or purpose of field observations was to determine the extent of corrosion on main trusses and stone connections for the Wisconsin State Capitol Dome.

Scope of work included field visual observations of the following:

- Main truss bottom pin connections for corrosion: Truss 18 and Truss 6
- Existence of a 2 inch cavity between exterior granite and terra cotta
- Granite stone connections for corrosion
- How the gutter (located at the bottom of the dome in the interstitial space) was flashed
- Main truss top & bottom chords, intermediate web members, and intermediate tee members for corrosion
- Review of existing drawings, document repairs made to plaster on the inside of the dome and document the present condition of plaster.

Observations and Findings: See Appendix A for dome truss location diagram, dome section and outer dome truss section.

Main Truss Bottom Pin Connections:
The truss pin connection for Truss 18 was opened and exposed. This truss connection is near where water damage was noticed on the inside of the dome. Light rust was observed on Truss 18 and it appears little moisture is getting to truss pins and the masonry is relatively dry around the truss pins. See Figure 1 below.

Figure 1: Truss 18 Pin Connection

An existing observation port at the truss pin connection for Truss 6 was opened and pin connection exposed. See Figure 2 and Figure 3 below. This truss pin connection had been exposed back in 1993 and left exposed for future observations and monitoring. An area on pin connection had been cleaned of rust to determine how fast corrosion would occur. Light rust was

also evident on this pin connection and again the conclusion is that little moisture is getting to truss pins and masonry around the truss pins.

Figure 2: Truss 6 Connection Box

Figure 3: Truss 6 Bottom Pin Connection

Granite Stone Connections:

Four connections were exposed in the following order by Capitol Maintenance Staff:

1. Truss 6 - 2nd connection from bottom: This truss and stone connection was chosen as water/corrosion was noticed during installation of dome monitoring instrumentation. Only light rust was observed at the stone connection indicating little moisture is getting to the connection. See Figure 4.

Figure 4: Truss 6 - 2nd Connection from the Bottom

2. Truss 16 - 1st connection from top: Heavy rust was observed at stone connection. Indicating that water was getting to connection. After exposing this connection it was decided to expose a connection lower on same truss. We also agreed to try a connection on another truss near the top. This connection was also corroded at the top chord similar to Truss 16.

Figure 5: Truss 16 - 1st Connection from the Top

3. Truss 16 - 2nd connection from bottom: Light rust was observed at stone connection indicating little moisture getting to connection.

Figure 6: Truss 16 - 2nd Connection from the Bottom

4. Truss 21 - 1st connection from top: Light rust was observed at connection indicating little moisture getting to connection.

Figure 7: Truss 21 - 1st Connection from the Top

2 inch Cavity:
The 2 inch cavity space between granite and terra cotta was filled with grout. We checked several locations located over the truss and at midspan between trusses. No open air space was observed. See Figure 8 below.

Figure 8: Filled 2 inch Cavity Space

Gutter (located at the bottom of the dome in the interstitial space)
A copper lined gutter is located at the bottom of the dome at the interstitial space. Some debris was found in gutter but drains and gutter were dry.

We also exposed gutter copper flashing located at base of trusses and found that copper flashing lapped into brick 3 ½ inches on the outside. The copper gutter flashing is not embedded into the terra cotta but is lapped 6 inches on the inside face. See Figure 9 below.

Figure 9: Gutter at Bottom of Dome

Corrosion on Truss Members:

We observed heavier corrosion on intermediate tee members between trusses (supporting terra cotta block). Location of heavier corrosion areas are on the north exposure of dome on trusses 14 to truss 21 near the top of the trusses (down to the 4th cross channel from the top of the trusses). See Figure 10 below. We also noticed some corrosion on the top chords of the trusses in the same areas (Figure 11). It appears that corrosion is less than 1/32 inch deep in most areas on tee members and light rust on top chords of trusses. No spalling of grout at terra cotta was noticed from corrosion.

Figure 10: Corrosion on Intermediate Tee Members

Figure 11: Corrosion on the Top Truss Chord

Light corrosion was noticed on all trusses and is probably occurring due to high humidity levels in the interstitial space.

Compression Ring:

Due to heavier corrosion on intermediate tee members and top chords of the trusses, it appears water has gotten into truss space. In talking with Mike Bath, he indicated that the new roof at base of the lantern was installed within the last four years. We did not inspect the compression

ring but asked when it had last been inspected. We understand that the compression ring was not inspected within the last ten years or after the new roof was installed at the base of the lantern.

Plaster on the inside of the outer dome:
The plaster surface at the base of the outer dome has evidently been problematic likely since the completion of original construction in 1914. Anecdotal evidence and actual in-field evidence indicate that the plaster at approximately the location of the brick wall corbel has been repaired at least several times.

Members of the project team have also reviewed original drawings and details of the dome and historic photographic images of original construction to better understand the construction of the dome and the interrelationship of the steel structure, masonry and granite cladding. Various reports and studies concerning the dome completed within the last fifteen years were also reviewed.

The last extensive repair and patching of the dome plaster was accomplished during the Restoration and Rehabilitation of the Rotunda in 1997 -1998. During this project a wood scaffold was erected around the interior perimeter at the base of the exterior dome. This facilitated comprehensive patching of the plaster surface. Once cured the surfaces were painted with an oil base primer and paint.

At the time of the work a video tape record was made of the process in this area as workmen removed loose and deteriorated plaster and prepared and replastered the surface.

Several of these tapes dated January 6 and January 11, 1998. Although workmen can be seen removing plaster and patching their exact location at the perimeter can not be determined. It is clear form the video tape record that in January of 1998 the amount of deterioration was very significant and that it was relatively evenly spread out in the areas at and just above the brick corbel.

The repairs to the plaster in this area of the dome apparently held up well for six years. Evidence of delamination of plaster surface at the base of the outer dome was first observed in 2002 by Capitol staff. The situation gradually worsened until today large areas are failing and the deterioration in some areas is significant. See Figure 12 and Figure 13 below.

Figure 12: Plaster Deterioration at Truss Location No. 5. Along the Exterior Wall of the Dome.

Figure 13: Plaster Deterioration at Truss Location No. 9 Along the Exterior Wall of the Dome.

On May 1, 2008, the deterioration was photographically documented. Photographs were keyed to the various trusses so that the deterioration could be tracked. The team is scheduled to photograph the surfaces again the first week of November which will be six months from the initial documentation. A comparison of locations and amounts of deterioration will be made and recorded. Apparent patterns of plaster failure will be documented.

The type of deterioration of the plaster away from the substrate indicates that moisture is the cause of the failure. The amount of moisture is not great but is evidently constant and consistent in nature. Various ways moisture could enter the dome base have been analyzed including; leaking gutters or downspouts, moisture vapor migration, open joints in the granite cladding and leaks in various roofs/decks. This investigation has not been able to pinpoint the source of the moisture, however a dominate cause has been identified.

Due to the significant thickness of granite and solid brick masonry at the location of the plaster deterioration, (in excess of 42 inches) and considering the slope of the exterior granite at this location, it is unlikely that exterior water, in the form of rain or snow, is a significant contributor to the problem.

Also, it does not appear that rain leader piping is leaking at any locations that would contribute to the problem.

Due to the observed dry conditions noted within the internal gutter of the dome, this potential source of water can also be eliminated from consideration.

It is more likely that warm moist outside air is slowly passing through the wall (from warm moist outside conditions to cooler dryer interior conditions) and over time condensation occurs at some location just inside the interior face of the wall. This condensation moisture breaks down the structure of the plaster and forces the non-preamble paint to peel away. The presence of efflorescence and small amounts of deposited salts are indicators of water migrating through the wall over time.

Summary and Recommendations:

Previous Phase I work:
Summarizing our evaluations completed during Phase I, we completed a thorough visual inspection of the dome and installed instrumentation to monitor the exterior dome, the interstitial dome space, and the internal dome for movement, temperature, moisture, and humidity. The instrumentation has been very slow in getting installed. The internal dome instrumentation and weather station have been installed and/or operational early 2008. Our observations/findings, conclusions, and recommendations are attached in the report dated January 15, 2008. See Appendix B. The monitoring of instrumentation is still on going.

Findings of Structural Phase II investigation:
During our presentation of the Phase I Report, we recommended that a structural evaluation be made of truss stone connections and truss pins at the base of the dome for deterioration and corrosion. Our findings are presented above. In summary we found the following:

- The bottom pin connections on trusses are in good condition with little corrosion observed.
- The truss stone connections are generally in good condition with little corrosion observed except in isolated conditions where leakage from the outside has occurred through the granite stone joints.
- Water leakage has occurred near the top of the dome from leaks in roofing at the base of the lantern. Corrosion has occurred on intermediate tee members between trusses and some light corrosion is occurring on top truss chord members especially on the north face of dome between trusses 14 to 21.
- Light corrosion is starting to occur on trusses probably due to high moisture in the interstitial space.
- The 2 inch space between terra cotta and exterior granite is grouted solid (and was used as a grout bed for exterior granite to set on during original installation.)
- Copper gutter at base of interstitial dome space is not flashed through the brick exterior wall.
- Deterioration of plaster has occurred since repaired in 1998. The worse deterioration is on south face between trusses 5 and 14.

Factors Contributing to Moisture & Humidity Problems:

In our research, it has become obvious that several factors have contributed to the moisture and humidity problems in the interstitial space as well as corrosion problems. The factors are as follows:

- Interstitial space is not vented to the outside except for four roof drains to the outside.
- Water has leaked into the interstitial truss space over the years due to leaking which has occurred at the roof at the base of the lantern, lantern windows and façade. This problem has caused corrosion and repairs to the compression ring, etc.
- Building is now air conditioned causing dryer cooler air to exist on inside of dome space during summer months.
- Building can and is being humidified during winter months with new mechanical system. Humidity instrumentation was installed in March of 2008 and we are continuing to monitor.
- Exterior repairs to the dome have resulted in using sealant rather than mortar for repair joints between granite stones, resulting in a tighter but a less breathable structure. Also at base of dome, several stone joints that were originally open have been caulked therefore reducing the ability of the base of the dome to breath.
- Some leaking through stone mortar joints has occurred over time.
- Interior of dome has been painted forming a nearly non-breathable membrane on inside face of terra cotta not allowing the moisture in terra cotta to dry out except from the inside of the interstitial space.

Recommendations and Conclusions:

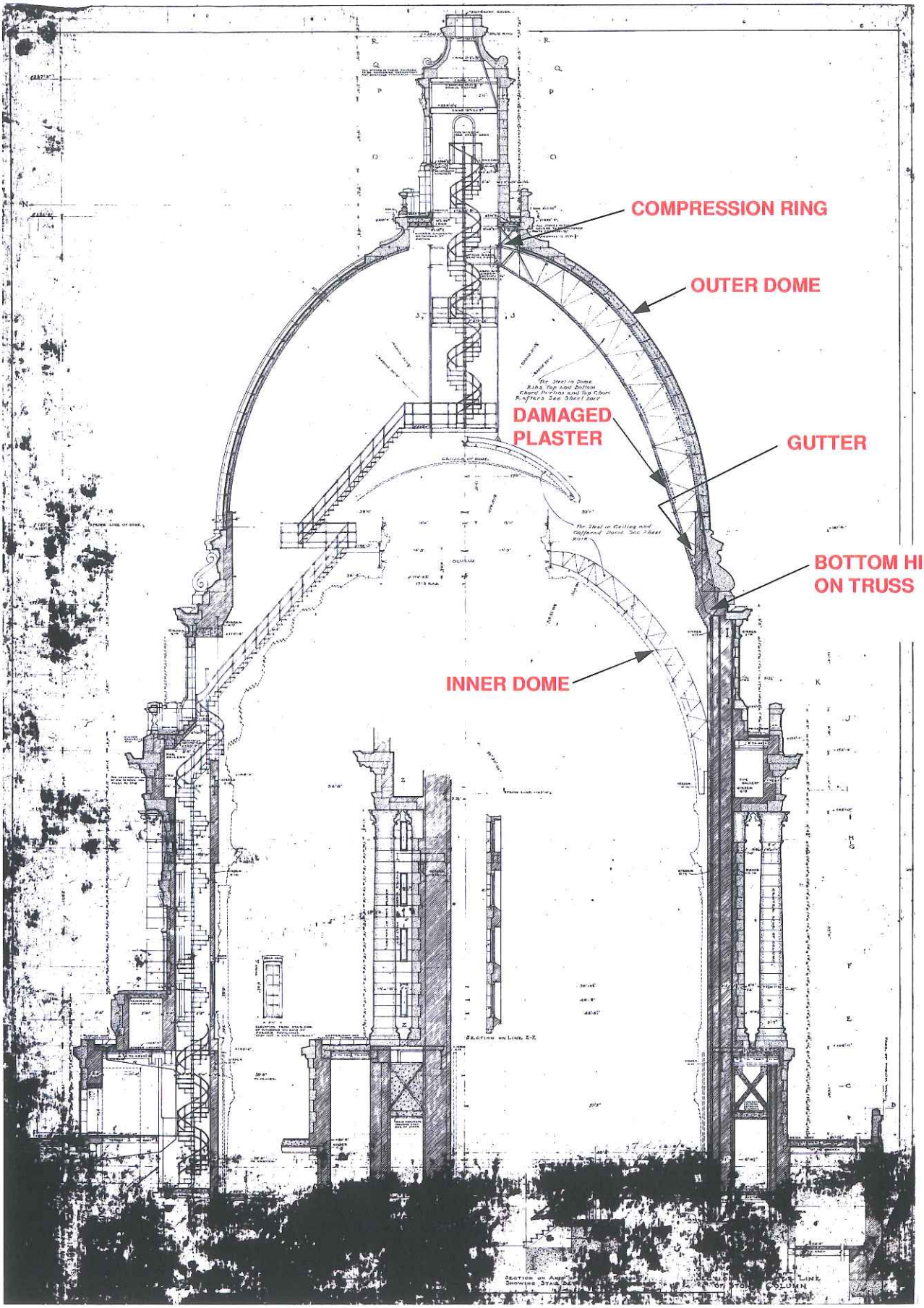
Our recommendations and conclusions to correct or minimize problems/factors identified above are as follows and **listed by priority of importance** (with 1 being highest priority):

1. We would recommend dehumidifying and/or ventilating the interstitial space and that this be installed by May 2009. We are presently recommending that a closed dehumidification system be installed. We also believe that high humidity is contributing to corrosion of trusses and intermediate tees between trusses. Therefore, we place this as higher importance than item #2 (inspecting, caulking and tuck pointing exterior of dome).
2. Exterior of dome be inspected, sealant be removed near base of dome and mortar joints repaired by 2009. We would also recommend that exterior granite on dome be inspected and mortar joints repaired every 10 years.
3. After the interstitial truss space has been dehumidified, we would recommend repairing the plaster on the inside and also possibly removal of paint on the lower 15 feet of the dome.
4. On-going monitoring of instrumentation over the next 5 years or longer. We want to adjust and fine tone dehumidification system for the interstitial truss system, adjust louvers and venting of internal space of dome for both humidity and temperature, and adjust/monitor humidity levels during the winter.
5. Field inspection of the compression ring at top of the dome to be completed as soon as possible to review and identify extent of corrosion from leakage from roof at lantern.
6. On going inspection every five years of roofing at base of the lantern and façade of the lantern for leaks and completion of repairs required. Assuming this roofing was installed in 2004, we would recommend that this inspection be completed in 2009.

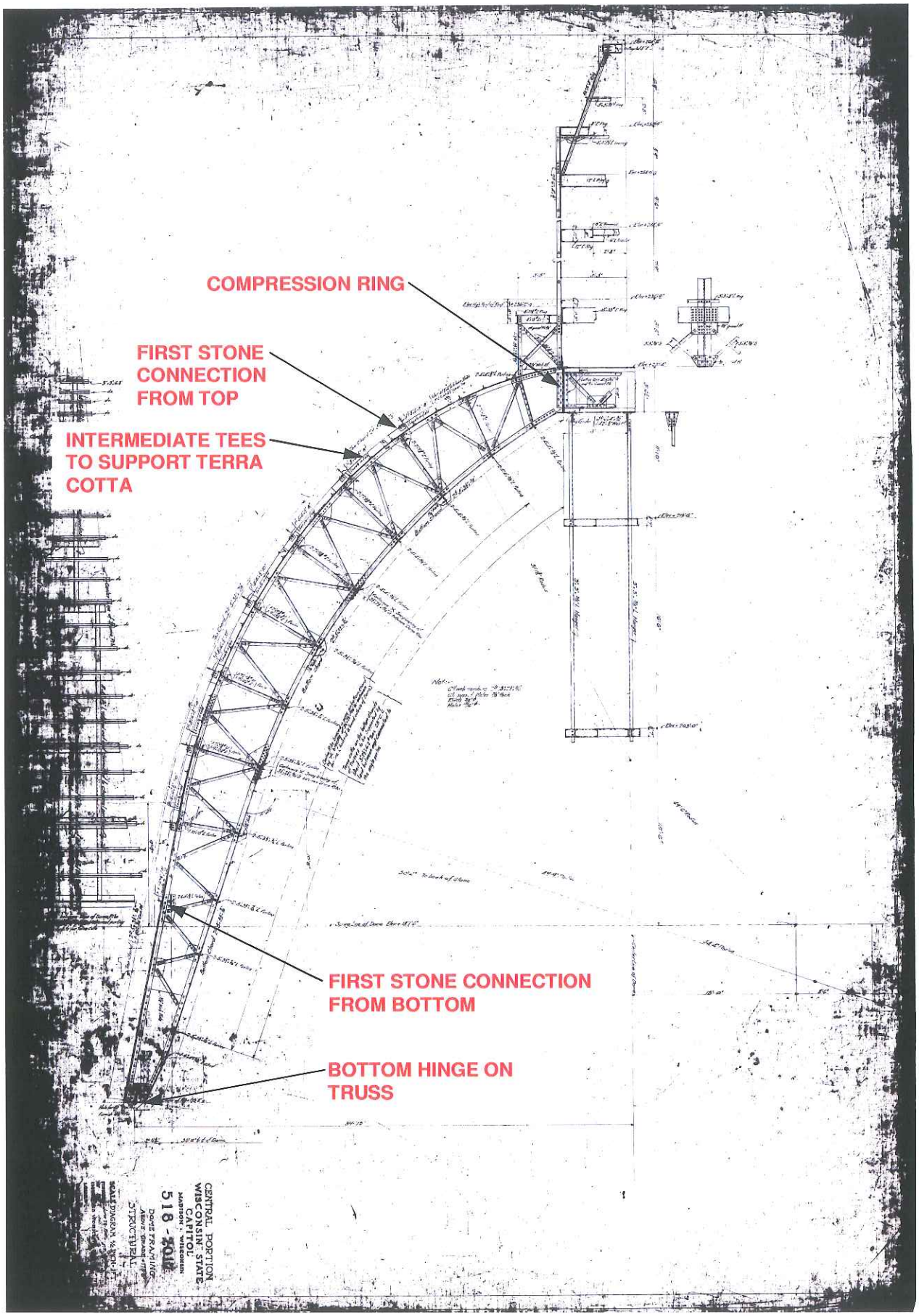
APPENDIX A

Dome Truss Location Diagram

Dome Section and Outer Truss Section



CAPITOL DOME SECTION



OUTER DOME TRUSS

GRAEF ANHALT SCHLOEMER and Associates Inc.

ISTHMUS ARCHITECTURE, INC.

APPENDIX B

Summary Report

Dated: January 15, 2008

Summary and Recommendations

Scope of Work

Our scope of work was to review original documents related to the construction of the drum and dome, review past studies completed on the dome and the state capitol, review maintenance records, interview building maintenance staff and contractors, field survey (visual observations) exterior dome for leaks, coordinate installation of instrumentation of dome, review of instrumentation data and preparation of report listing immediate remedial repairs and long-term maintenance/repairs.

Instrumentation of the dome was proposed by Graef, Anhalt, Schloemer & Associates, Inc. (GASAI) to review the monitor temperature and movement of the dome trusses due to the wind and temperature, humidity/moisture/temperature at interstitial truss space (between top chord and bottom chord of dome trusses), and exterior granite/terra cotta 2 inch vent space and on inside of the dome and rotunda. This data was criteria in finding out what was happening in these spaces so a solution could be recommended to solve the high humidity, deterioration of the inside face of outer dome plaster and corrosion on dome trusses. Installation of temperature probes and movement probes were installed by Ropelink (sub-consultant to GASAI). In October of 2005 and all other instrumentation was installed by the State Capitol maintenance staff in December 2005, February 2006, and re-installed in July 2007 the weather station added at top of dome to monitor the outside temperatures and humidity along with humidity/temperature/moisture probes on the inside of dome and rotunda.

Team

Graef Anhalt Schloemer & Associates, Inc. (GASAI): Lead Engineering Role
Isthmus Architecture, Inc. (IAI): Expertise in Preservation architecture
Ropelink: Vertical Access Specialists

History of Dome Construction and Repairs/Maintenance

After our review of original documents, repairs/maintenance records on dome, interviews with the building management staff and various contractors, the following is a brief summary in chronological order from initial construction of dome to repairs and maintenance over the years on dome:

- 1913 – 1914 granite installed on dome
- Dome exterior completed in July 1914.
- Dome re-pointed in 1957, 1960, 1962 and 1966.
- Capitol exterior cleaned with hydrofluoric acid 1964
- Dome interior painted with water based paint 1968
- Truss space inspected and water leaks noted in 1981
- Dome compression ring repaired in 1982
- Dome re-caulked 1993
- WJE Exterior survey and survey of truss space in dome, 1993
- Temperature/humidity study of North and South wings 1993
- Dome re-caulked 1996.
- Interior plaster repairs to dome 1997
- Vermont State geologist visits. Granite exfoliation inspected. 1999.
- Interior plaster deterioration first notices in 2000.
- Truss space walk through in February 2004, corrosion noticed on steel dome trusses.
- High humidity noted in truss space in July 2005.
- Exterior inspection of dome in October 2005.

Findings

Exterior dome survey (field observations completed in October 2005)
At a review and inspection of the exterior of the dome, no water leakage was found. All stone mortar joints were tight and caulk was in generally good condition. All exterior gutters were water tested and found not to be leaking.

We did observe near the base of the dome that stone joints had been caulked and a small ½ inch plastic tube was added. The plastic tubes and caulking severely limit the ventilation of the 2-inch cavity between the outer granite and terra cotta. At the top of the dome, we could not find the same 2-inch cavity vented. We studied original Post drawings and found no reference to the venting of a 2-inch cavity. It is our belief that the Post would have vented cavity space probably at both the bottom and top of the cavity space (bottom of lantern and bottom of dome) (drum).

Interstitial truss survey (field observations completed in August 2007)
On August 24, 2007, GASAI completed a visual inspection of the interstitial truss space to check for the presence of water infiltration from heavy rains that had occurred during late July and early August. On the day of the visual inspection heavy rains had just occurred in early morning (over 1 inch of rain). No evidence of water was found leaking during this afternoon. Drainage was through the bottom of interstitial space in the area near the drain was damp. Moisture was noticed on the truss top chord where the steel chord penetrates exterior masonry brick wall at the bottom of the truss. Light corrosion could be seen on truss top chords of trusses especially near the top of the dome.

Instrumentation
The relative humidity of the 2-inch cavity space remains nearly constant at about 80% throughout the year. Over time it appears that the relative humidity of the 2-inch cavity space exceeded the relative humidity of the outdoors.

The relative humidity of the interstitial truss of the space varies from a low of approximately 50% during the winter to a high of approximately 80% during the summer. The relative humidity in the interstitial truss space changes slowly over a period of several days.

The humidity ratio in the interstitial truss space of a 2-inch cavity space largely according to the season with the coldest months having the lowest moisture contents. The humidity ratio in these spaces was found to be consistently higher than the outdoor humidity ratio regardless of the season.

The steel temperature of the trusses was never found to be below the dew point temperature of the truss air. During the summer months the temperature difference between the surface of the steel and the dew point of the surrounding air generally varied between 5 to 7 degrees F. During the winter months the temperature difference was generally between 12 to 16 degrees F.

During the period of analysis there were 816 hours out of 12,138 where the surface temperature of the exterior granite was below the dew point temperature of the outside air. Condensation would be expected to form on the outside of the granite during these periods.

Interpretation of Data

Water Vapor Diffusion from the 2-inch cavity Space

It appears that on average, water vapor diffusion is generally moving water vapor from the 2-inch cavity space to the outdoors. It also appears that water vapor diffusion is moving water vapor from the 2-inch cavity space to the interstitial truss space. As mentioned, air movement may play a role in this as well, but we do not have enough information to know. Sealing and caulking has been done on the dome exterior, and if this has not completely prevented water ingress, it may be counterproductive, because it may inhibit vapor diffusion from the 2-inch cavity space to the outdoors. If the high relative humidity found year-round in the 2-inch cavity space is not migrating outdoors, it is more likely to migrate to the interstitial truss space instead.

Water Vapor Diffusion from the Interstitial truss space

It appears that water vapor in the interstitial truss space generally has one direction to move, which is to the indoors. This is because the other space adjacent to the interstitial truss space, the 2-inch cavity space, nearly always has a higher vapor pressure than the interstitial truss space. The recent addition of oil based paint to the plaster of the dome may have exacerbated the moisture problems within the dome. Oil based paints generally have lower water vapor permeability than latex paint, meaning that oil based paints impeded the passage of water vapor more than latex. The additional paint may slow the passage of water vapor from the interstitial truss space to the indoors, so more water vapor will build up within the plaster, and the relative humidity of the interstitial truss space will generally be higher than it otherwise would have been. Higher moisture contents within porous plasters have been linked to mold, plaster deterioration, and peeling paint. Some of these symptoms of high moisture content have been observed in the dome plaster.

It should be noted that there is an access door which connects the inner dome space to the interstitial truss space. The access door was installed about five years ago. Before the access door was installed, the access opening may have not have been covered, and if it were not it would have allowed free passage of convective air currents and water vapor between the two spaces.

Condensation on the Trusses

Although we did not record any instances of condensation occurring on the steel truss, we cannot necessarily conclude that it never happens. Steel surface temperatures were collected from within the interstitial truss space. Now we know that the 2-inch cavity space nearly always has a higher relative humidity and lower temperature. Like a hot frying pan with a relatively cool handle, it is possible, and probably likely, that during certain times of the year the steel in contact with the exterior granite is colder than the steel surface temperatures where the sensors were located. Condensation could still occur, and this would be consistent with observed corrosion.

Condensation on the Granite

The exterior temperature of the granite was found to condense water vapor from the outdoor air at times. Condensation could form in the joints as well as on the surface. Regardless of whether wind driven rain is forcing water through the dome exterior, it is possible that moisture is migrating from the outdoors to the indoors simply through condensation.

The porous nature of the granite, terra cotta, and plaster, would tend to retain some of this moisture. This is a possible explanation to why the moisture content inside the dome spaces is occasionally higher than found indoors or outdoors.

Recommendations

Building operators have indicated that from October to March the wings of the Capitol are humidified to a supply air relative humidity setpoint of 45% to 50% as the outdoor temperature drops from 55 degrees F to minus 15 degrees F. A common cause of moisture problems in buildings during the winter is excessive indoor humidity. The indoor relative humidity was uncollected, but based on the humidification control indicated, it is reasonable to suspect that the high humidification setpoints may adversely affect the dome during the winter. The lower level of comfort for people is 25% relative humidity. We recommend that the current HVAC control sequences be modified so that the upper relative humidity setpoint is 30% at an outdoor temperature of 55 degrees rather than 45%. Of course other factors beyond the scope of this report, such as static electricity control in sensitive areas, and deleterious affects on murals and paintings should also be considered by the owner before implementation.

Building operators have indicated that the louver on top of the dome was once controlled to open at an indoor temperature of 75 degrees F, and very recently it was changed to open at 90 degrees F instead. In order to control the humidity of the inside space, the damper operation should not solely be controlled by temperature, but also by indoor relative humidity. The damper should be closed at a designated temperature, but above that temperature should modulate open if the indoor relative humidity begins to rise.

We recommend that 2-inch cavity space between exterior granite and terra cotta be vented. Caulk at the base of the dome should be removed and venting near top of dome installed. We also recommend that at 6 to 8 locations, the truss/exterior granite connections be exposed to evaluate extent of corrosion to steel granite connections.

The interstitial truss space has a copper gutter with drainage lines. The copper gutter should also be examined and cleaned.

We would recommend that interstitial truss space be mechanically dehumidified. Two electric dehumidifiers could be installed on the platform near the oculus. Ducts would draw humid air from the interstitial truss space, and supply dehumidified air to the same space.

We would recommend that the 2-inch cavity space, interstitial truss space, and interior dome temperature and humidity, be monitored over next two years as a minimum to determine if mechanically dehumidification is working and not causing condensation of moisture in other areas. We would also recommend that a further study be completed on pressure gradients (pressure differentials) within the dome.

If after monitoring for two years the interstitial truss space is interior of dome, we find that existing paint is still not allowing interstitial space to breath and trapping/holding water in masonry, then we will recommend removal of all paint from interior plaster at terra cotta located at bottom of

main dome trusses. Plaster should be repaired and new white plaster applied that is breathable (allowing passage of moisture within terra cotta).

As ongoing maintenance, we would also recommend that exterior granite on the dome be inspected, all sealant removed, and mortar joints repaired and/or replaced in 2010. We strongly recommend that sealant not be used. Thereafter we would recommend that exterior granite on the dome be inspected and mortar joints repaired every 12 to 15 years.