



MITCHELL PARK HORTICULTURAL CONSERVATORY DOMES Peer Review

Milwaukee, Wisconsin



Final Report

March 14, 2017

WJE No. 2016.2700

Prepared for:

National Trust for Historic Preservation

53 West Jackson Boulevard, Suite 350

Chicago, Illinois 60604

Prepared by:

Wiss, Janney, Elstner Associates, Inc.

10 South LaSalle Street, Suite 2600

Chicago, Illinois 60603

312.372.0555 tel | 312.372.0873 fax



**MITCHELL PARK HORTICULTURAL CONSERVATORY
DOMES
Peer Review**

Milwaukee, Wisconsin

A handwritten signature in black ink, reading "Peter T.", is positioned above a horizontal line.

Peter Tarara, PE, SE
Associate Principal and Project Manager

A handwritten signature in black ink, reading "B. S. Kaskel", is positioned above a horizontal line.

Bruce S. Kaskel, RA, SE, LEED AP
Principal

Final Report

March 14, 2017

WJE No. 2016.2700

Prepared for:

National Trust for Historic Preservation

53 West Jackson Boulevard, Suite 350

Chicago, Illinois 60604

Prepared by:

Wiss, Janney, Elstner Associates, Inc.

10 South LaSalle Street, Suite 2600

Chicago, Illinois 60603

312.372.0555 tel | 312.372.0873 fax

TABLE OF CONTENTS

Executive Summary	1
Introduction.....	2
Background	2
Document Review.....	3
1959 Original Drawings.....	4
GRAEF Reports	9
Precast Framing	9
Glass Cladding.....	10
September 23, 2016 Meeting.....	10
Precast Framing	10
Glass Cladding.....	10
Observations.....	11
Precast Framing	11
Glass Cladding.....	13
Discussion and Conclusions.....	14
Precast Framing	14
Glass Cladding.....	15
GRAEF Repair Options.....	15
Recommendations	16
Precast Framing	17
Glass Cladding.....	17
Cost Estimate	18
Closing	19
Appendix A - Summary of GRAEF Reports	20
1994 GRAEF Report.....	21
2004 Asset Report	23
2008 GRAEF Report.....	23
2013 GRAEF Letter	25
2015 GRAEF Report.....	25
May 2015 GRAEF Letter (<i>reported by GRAEF</i>)	27
July 2015 GRAEF Letter.....	28
February 2016 GRAEF Letter	28
February 2016 Presentation (reported by Milwaukee County)	29
March 2016 Presentation (reported by Milwaukee County)	29
May 2016 Presentation (reported by Milwaukee County)	29
2016 GRAEF Report.....	29

MITCHELL PARK HORTICULTURAL CONSERVATORY DOMES

Peer Review

Milwaukee, Wisconsin

EXECUTIVE SUMMARY

The Mitchell Park Horticultural Conservatory complex consists of three large domes, a central lobby area, and a transitional greenhouse. Construction of the complex began in 1959 and proceeded in stages with the Show Dome opening in 1964, the Tropical Dome in 1966, and the Arid Dome in 1967. The domes are glass-and aluminum clad with a structural precast concrete frame arranged in triangular patterns to form a conoid-shape dome. GRAEF has been providing architectural and engineering consulting services to Milwaukee County on the domes since 1993. This report summarizes our peer review of GRAEF's work, our evaluation, and provides an estimated cost for a conceptual repair option for the exterior glass cladding and precast concrete framing members.

Overall, the glass cladding and precast concrete have performed well considering that minimal maintenance and repairs have been completed on the domes. The primary issues are water leakage and spalling concrete at the embedded connections. Based on our observations and experience with similar structures, it is our opinion that the domes can be preserved and restored. Past repairs have not addressed water leakage into the domes.

GRAEF has provided five restoration options (Options 1 to 5) and a replacement in-kind option (Option R) with estimated costs ranging from \$14 to \$64 million. Option 1 replaces broken glass, addresses water leakage, and repairs the precast concrete framing. Option 1 also retains most of historic fabric of the dome structures and maintains the existing appearance. The primary difference with Options 2 through 4 when compared to Option 1 is the use of coated insulating glass at a cost of approximately three to four times the repair cost of Option 1. The only cost difference between Options 1 and 2 is the replacement of all wired glass with coated insulating glass at an additional cost of \$24 million. WJE does not recommend the use of coated insulating glass because the cost savings are slight compared to the initial investment, and coated insulating glass is not beneficial for plant life.

Based on the options presented by GRAEF and our observations, Option 1 seems to be the most viable option with several considerations for enhancing the repair option proposed by GRAEF. Additional laboratory analysis of the concrete should be performed prior to selecting a coating system. At locations where the wired glass is broken, we recommend replacement with in-kind or laminated glass. For better weather protection, removing and replacing the pressure caps with a new redesigned pressure cap will allow a wet seal to supplement the new glazing seal. We believe that this redesign would largely resolve rain water leakage through the domes, which is the primary issue and cause of spalling concrete at connections. WJE's estimated cost to repair all three domes is approximately \$18.6 million, which is greater than GRAEF's estimate of approximately \$14.0 million for a similar scope of repair items as outlined in GRAEF Option 1. The primary difference in the higher cost is related to replacing all the pressure caps on each dome, which we believe will provide better weather protection, increase the service life of the domes, and provide a long-term repair.

The Mitchell Park Horticultural Conservatory Domes are unique, architecturally significant structures that have performed well during their first fifty-eight years of service life and can be preserved. The condition of the precast concrete framing and glass cladding is repairable, and replacement of these systems is not necessary at this time.

MITCHELL PARK HORTICULTURAL CONSERVATORY DOMES

Peer Review

Milwaukee, Wisconsin

INTRODUCTION

At the request of the National Trust for Historic Preservation, Wiss, Janney, Elstner Associates, Inc. (WJE) performed a peer review of consulting work completed on the Mitchell Park Horticultural Conservatory Domes (commonly referred to as “the domes”) in Milwaukee, Wisconsin. GRAEF has been providing architectural and engineering consulting services to Milwaukee County on the domes since 1993. The purpose of the peer review was to review GRAEF’s work related to the exterior glass cladding and precast concrete framing members, including repair cost estimates. In addition, this report summarizes our findings and provides an estimated cost for a conceptual repair option for the exterior glass cladding and precast concrete framing members.

BACKGROUND

The Mitchell Park Horticultural Conservatory complex consists of three large domes, a central lobby area, and a transitional greenhouse (Figures 1 and 2). Construction of the complex began in 1959 and proceeded in stages with the Show Dome opening in 1964, the Tropical Dome in 1966, and the Arid Dome in 1967. The architect of record was Donald L. Grieb Architects and the structural engineer of record was Charles S. Whitney, Consulting Engineer. Donald L. Grieb, a local architect, won a design competition for his glass domes entry. Super Sky Products Enterprises, LLC (Super Sky) was the designer and installer of the glass and aluminum structure that clads the domes. Each dome contains a distinct microclimate and exhibits plants in a naturalistic setting. The Show Dome is used for rotating seasonal horticultural exhibits, while the microclimates of the Tropical Dome and Arid Dome remain constant year round. The domes are glass- and aluminum clad with a structural precast concrete frame arranged in triangular patterns to form a conoid-shape dome. The precast concrete members were fabricated onsite during construction. The domes are supported on circular, reinforced concrete foundation walls. The glass and aluminum framework is connected to the precast concrete frame with stainless steel connection posts. The original glass is mostly intact, and is wire reinforced glass (wired glass).

Based on inspection reports by GRAEF, primary issues with the domes have included: water leakage from the exterior glass; issues with the internal drainage system of the cladding; concrete deterioration at connection plates embedded in the precast concrete members; and periodic glass breakage. In 2013-2014, GRAEF performed a close-up inspection and subsequent repair of all precast concrete members. The repair primarily consisted of removing loose concrete at embedded connection plates, and cleaning and painting the connection plates. More recently, a stainless steel mesh netting was installed beneath the precast concrete members to mitigate falling concrete. At this time, GRAEF has provided options to repair the three domes with estimated costs ranging from 14 million to 64 million dollars. We understand that Milwaukee County is reviewing options for the future of the domes.



Figure 1. Overall view of the domes



Figure 2. View of the Show Dome

DOCUMENT REVIEW

WJE's peer review included review of the following documents. We have provided our summary of pertinent information from the GRAEF letters and reports, and the Milwaukee County presentations, in Appendix A.

- Original design drawings titled "Mitchell Park Conservatory" for the Milwaukee County Park Commission, dated January 15, 1959 (1959 Original Drawings)
- Report titled "Structural Condition Study of the Mitchell Park Domes" by Graef, Anhalt, Schloemer & Associates (GAS), Inc., dated February 7, 1994 (1994 GRAEF Report)
- Master Plan for Mitchell Park & Horticultural Conservatory by Engberg Anderson Design Partnership, Inc., dated November 10, 2000
- Asset Detail Report by Asset Name, VFA, Inc., dated October 19, 2004 (2004 Asset Report)
- Letter by GAS, dated December 14, 2006, regarding structural review of the domes after a nearby explosion
- Report titled "Show Dome Facade Study and Lower Level Facade Study" by GAS, Inc., dated October 10, 2008 (2008 GRAEF Report)
- Letter by WJE, dated April 7, 2009, regarding structural review of the domes after a nearby explosion
- Letter by GRAEF, dated September 10, 2013, regarding phase 1 concrete frame evaluation (2013 GRAEF Letter)
- Report titled "Tropical, Desert, and Show Dome Inspection Report" by GRAEF, dated January 15, 2015 (2015 GRAEF Report)
- Letter by GRAEF, dated May 15, 2015, regarding falling of small debris (May 2015 GRAEF Letter)
- Letter by GRAEF, dated July 28, 2015, regarding 2015 assessment (July 2015 GRAEF Letter)
- Letter by GRAEF, dated February 8, 2016, regarding visual assessment of the Desert Dome (February 2016 GRAEF Letter)
- Presentation by Milwaukee County Parks Department and Facilities Department at February 24, 2016 Domes Public Hearing (February 2016 Presentation)
- Presentation by Milwaukee County Parks Department and Facilities Department at March 8, 2016 County Board Parks Committee meeting (March 2016 Presentation)
- Presentation by Milwaukee County Parks Department and Facilities Department at May 17, 2016 County Board Parks Committee meeting (May 2016 Presentation)
- Report titled "Mitchell Park Horticultural Conservatory - 2016 Update on Costs and Options for Domes" by GRAEF, dated November 10, 2016 (2016 GRAEF Report)

1959 Original Drawings

1. The domes are approximately 142 feet in diameter at their bases and 75 feet high from the finished floor lobby.
2. The apex of the domes is constructed of an aluminum structural skylight. A hatch provides access to a walkway that circles the dome at the apex. This was designed to facilitate exterior access and future maintenance.
3. Concrete compressive strength is specified to be 3,000 psi (assumed to be for cast-in-place concrete).
4. Reinforcing steel is specified to be of intermediate grade (assumed to be for cast-in-place concrete).
5. The precast concrete frame is comprised of eleven space frame member types (Figure 3). The assembly repeats around the domes 25 times.
6. Precast concrete members are trapezoidal, with the width at the top of each member typically 1/2 inch wider than at the base.
7. Precast concrete members vary in size from a width between 3 inches and 6-1/2 inches, and a depth of 6 or 8 inches (Figure 4). Precast members are reinforced with two longitudinal bars, one each at the top and bottom of the member. The size of the reinforcing bars range from No. 6 to No. 10 bars. The side concrete cover is over 1 inch on smaller members and approximately 2-1/2 inches on larger members.
8. Precast concrete members are attached together at joints by welding the end of reinforcing bars in the precast to a gusset plate (Figure 5). Grout is installed over the plate and into the keyway between the precast members.
9. Adjacent precast concrete members are attached together by welding a 6 inch long, 3/4 inch diameter rod between embedded plates in each member (Figure 6).
10. The glass is specified to be 1/4 inch patterned wired glass manufactured by the Mississippi Glass Co., St. Louis, Missouri.
11. The glass is held in place with a pressure cap and fasteners (Figure 7).
12. The circular hub is welded to an embedded plate in the precast concrete members (Figure 8). The embedded plate in the precast members is flush with the surface of the concrete.
13. Aluminum rafters which are part of the cladding drainage system frame into the circular hubs (Figure 9). The hubs have an exterior cover that was originally set in a mastic or sealant. Water is intended to flow down the rafters at each hub. The opening in the downspout rafter (the rafter that extends downward from the hub to the adjacent hub) is slightly higher than the base of the hub.

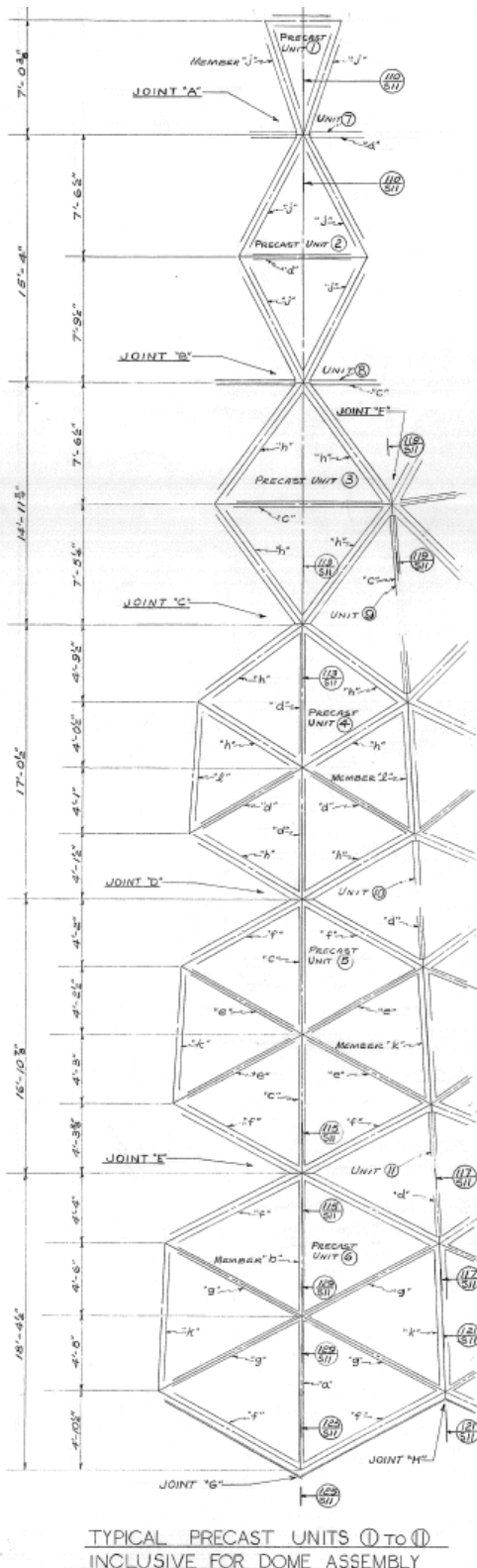


Figure 3. Typical precast concrete members
- reproduced from original drawings

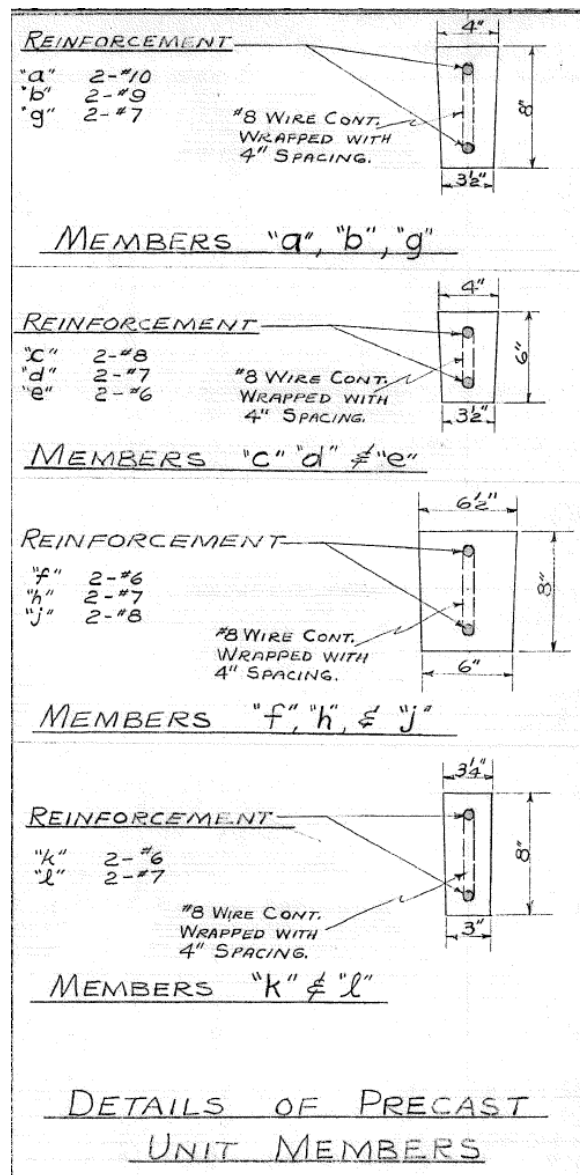


Figure 4. Details of precast concrete members and
reinforcing - reproduced from original drawings

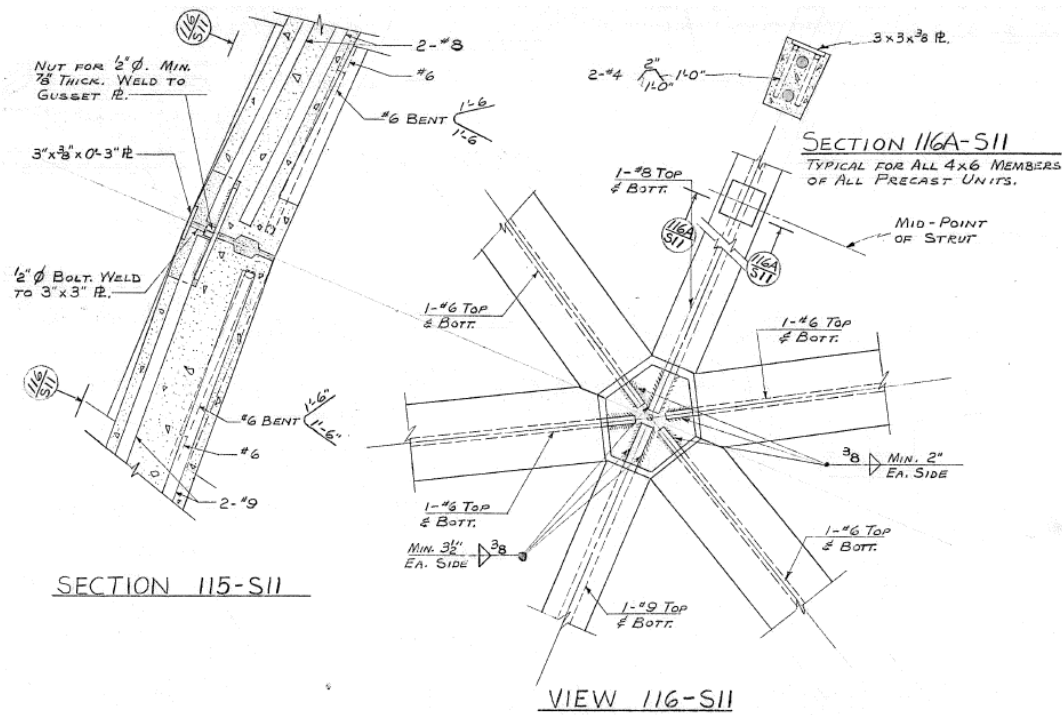


Figure 5. Typical precast concrete member connection at joint - reproduced from original drawings

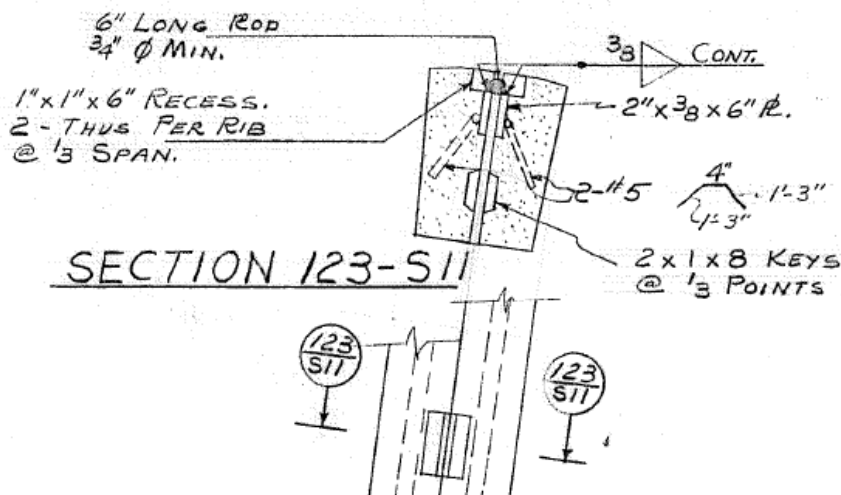


Figure 6. Typical precast concrete connection between members - reproduced from original drawings

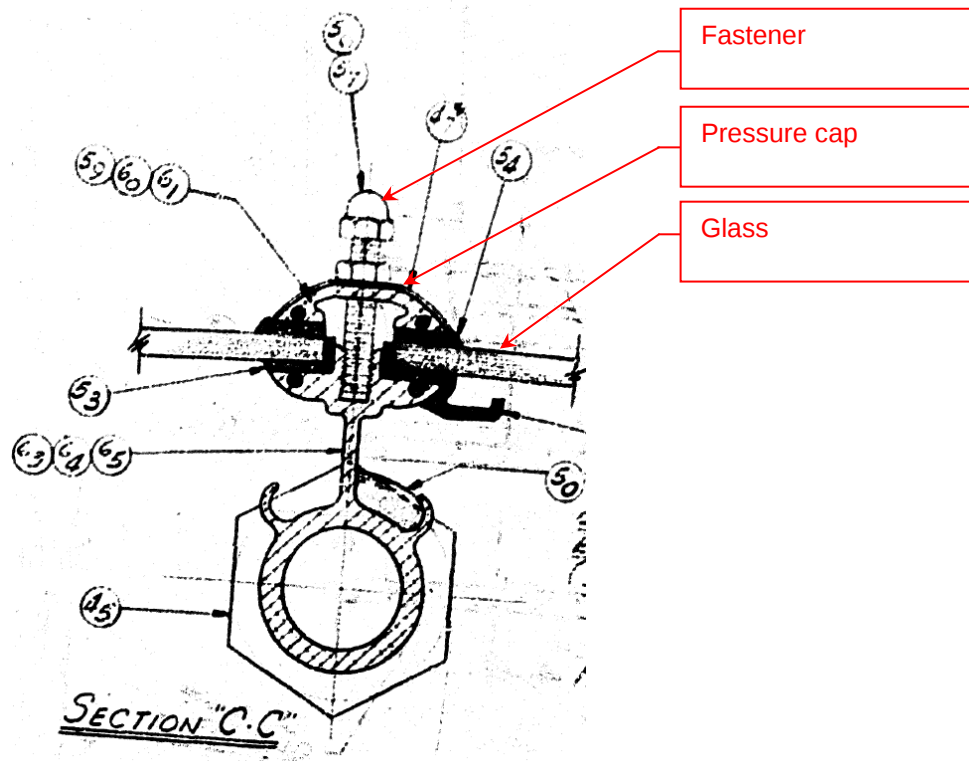


Figure 7. Section through glass and aluminum frame

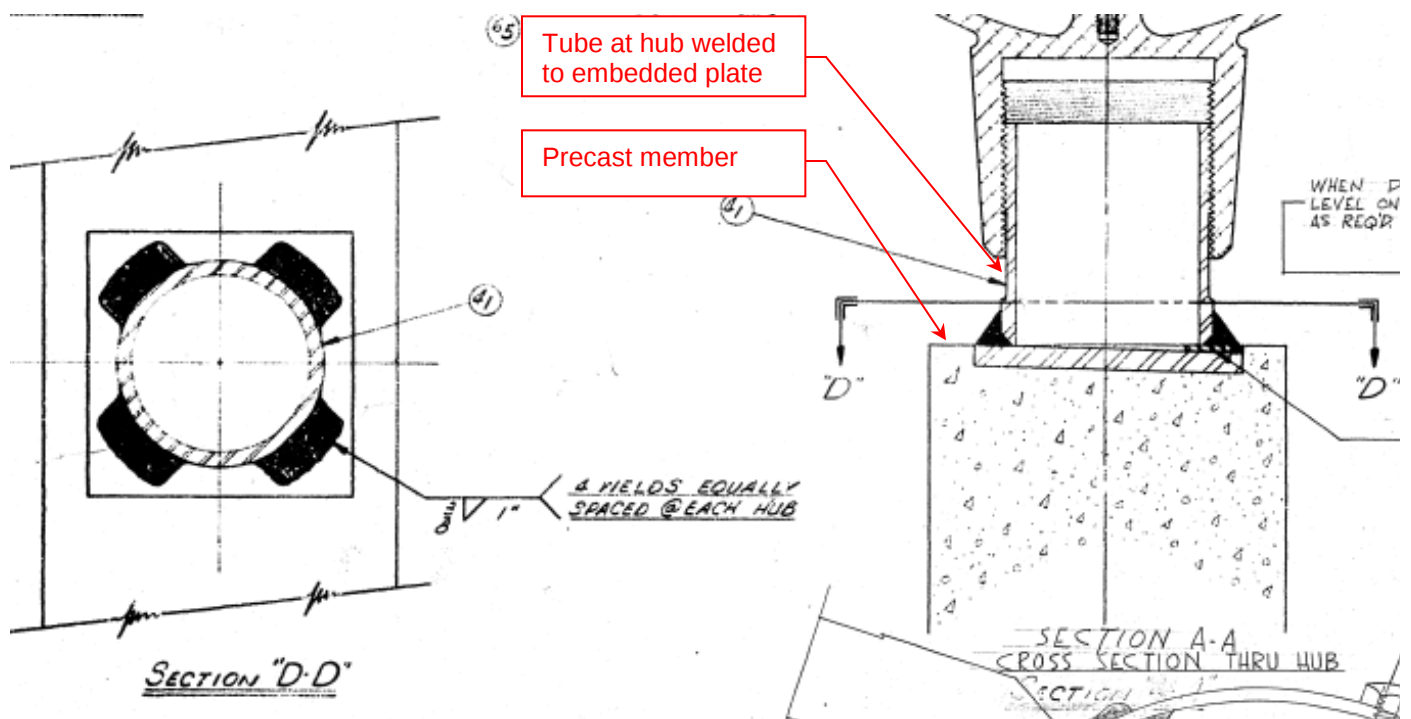


Figure 8. Section through hub from original drawings showing hub welded to embedded plate in precast concrete member

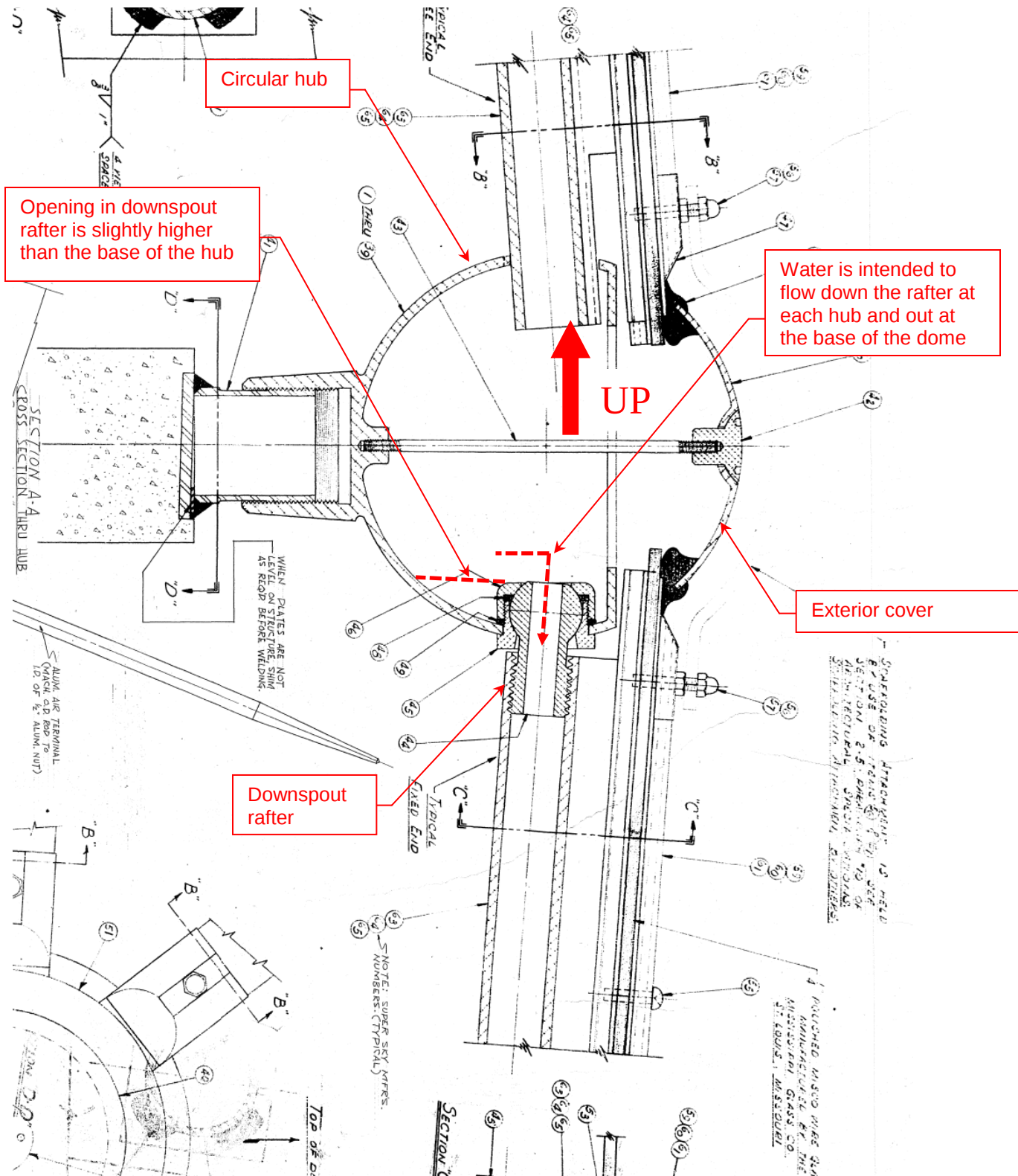


Figure 9. Section through hub from original drawings showing hub cladding drainage system

GRAEF Reports

GRAEF has provided five restoration options (Options 1 to 5) and a replacement in-kind option (Option R), with estimated costs ranging from \$14 to \$64 million. GRAEF options include:

1. Option 1: Replace broken glass, repair cladding and concrete frame.
2. Option 2: Replace all glass with coated insulating glass (some of the recommended insulating glass has a low-E coating for improved energy performance), repair cladding and concrete frame.
3. Option 3: Replace all glass with coated insulating glass and install new cladding supported on repaired concrete frame.
4. Option 4: Install new coated insulating glass and new self-supporting cladding system, and repair concrete frame.
5. Option 5: Install new coated insulating glass and new self-supporting cladding system, and remove concrete frame.
6. Option R: Install new cladding system with coated insulating glass and rebuild concrete frame per original construction.

GRAEF provided estimated costs, estimated life, maintenance level, and stated whether the installed mesh should remain in place for each option as summarized in the following table.

Option	Estimated Cost	Estimated Life	Maintenance	Wire Mesh
1	\$14 million	5-10 years	Very High	Remains
2	\$38 million	15-20 years	High	Remains
3	\$47 million	25-30 years	High	Remains
4	\$54 million	25-30 years	High	Remains
5	\$50 million	50 years	Normal	Removed
R	\$64 million	50 years	Normal	Removed

Information on the determination of estimated life was not provided in the report. GRAEF defined the maintenance as follows:

- Very high maintenance: requiring frequent (annual) inspections to monitor the condition of the concrete frame, and periodic repairs (one to three years) to address broken glass, cleaning rafters and hubs, and plant maintenance as it is affected by water leakage
- High maintenance: frequent (annual) inspections to monitor the condition of the concrete frame, and periodic repairs (three to five years) to clean the drainage system
- Normal maintenance: periodic (five years) inspections to monitor the condition of a new structural system

Additional comments on the precast framing and glass cladding from our review of the GRAEF reports are provided below.

Precast Framing

- The conditions observed in each of the GRAEF reports are very similar. The amount of concrete spalls at embedded plates has increased over time. To date, over 40 percent of the embedded plates had spalls, and the spalls have been removed. Also, the embedded plates at removed spalls have been cleaned and painted.
- Cracks were reported between precast members, and between the concrete base and precast members.
- The recommended coating systems for the precast concrete include an epoxy system and a stain.
- The greatest amount of spalling was observed in the Desert Dome.

Glass Cladding

- Approximately 400 units of cracked glass are estimated for replacement in Option 1 for each dome.
- An energy study indicates that the Mitchell Park Domes would realize a savings of approximately \$110,000 per year with one of the recommended types of coated insulating glass. This savings assumes no changes to the current HVAC system.

September 23, 2016 Meeting

On September 23, 2016, WJE met with representatives of NTHP, Milwaukee Preservation Alliance (MPA), Milwaukee County Parks staff, Milwaukee County Engineering, GRAEF, and Berglund Construction (Berglund). The following is a summary of the significant information from the meeting:

Precast Framing

- Concrete spalls were removed by a contractor at locations identified by GRAEF at approximately 40 percent of the embedded connections in 2013 and 2014. All areas were accessed using an articulating lift. The project cost was approximately \$500,000, not including costs associated with plant life.
- Since 2015, Milwaukee County Parks staff has collected small fragments of concrete on the ground around the domes on several occasions (Figures 10 and 11).
- A stainless steel mesh netting was being installed at the time of the meeting on the interior facing surface of precast members to mitigate falling concrete in the Arid Dome. Netting installation in the Show Dome and Tropical Dome was completed.
- GRAEF reported that a longer term repair may include proactively removing potential concrete spalls at embedded connection plates, along with cleaning and painting the plates. The mesh could remain in place once the long-term repairs are completed.
- The concrete coating on the precast members has failed at most locations. Coating options were briefly discussed.

Glass Cladding

- GRAEF presented five (5) restoration options for the glass cladding in their 2008 report. GRAEF reported that all of these options were still being considered as of 2016. Depending on the option(s) chosen, code requirement could be “triggered” which could require the structure to be upgraded to current code requirements.
- Coated insulating glass units were being considered as long as the existing system can support the additional loads. In 2008, GRAEF performed preliminary analysis which indicated that the frame could support the additional glass weight. As of 2016, GRAEF indicated that they would need to evaluate this further.
- Milwaukee County Engineering reported that cracked glass has been replaced in the past using a crane. The glass needs to be field measured for replacement. Due to shifting of the aluminum cladding frame over time, glass pieces cannot be assumed to be the same size.
- A new greenhouse has been recently built behind the three domes. This new structure has made exterior access to the domes from grade level for routine maintenance, such as glass replacement, more difficult. GRAEF had provided a conceptual option in one of their earlier reports to access the exterior from the original apex walkway using a specialty work cart hung from cables. However, costs for accessing the exterior have not been obtained recently by GRAEF.
- GRAEF reported that water leakage throughout the domes has historically been a problem and still remains an ongoing issue. GRAEF reported that water was observed sitting in the hub and not allowed to drain. They attribute this problem as due to the fact that the downspout rafter extends higher than the base of the hub (see Figure 9).



Figure 10. Fragments of concrete collected by Milwaukee County Parks staff

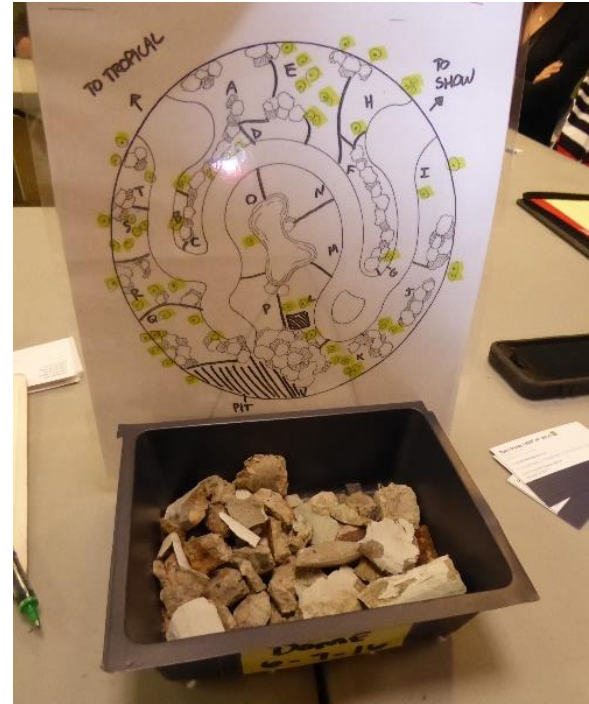


Figure 11. Close-up of fragments of concrete collected by Milwaukee County Parks staff

Observations

On September 23, 2016, Bruce Kaskel and Peter Tarara of WJE performed a walk-through of the Show Dome and Arid Dome to visually observe conditions from grade level and the perimeter catwalk. Paving work was being performed in the Tropical Dome, which was therefore not accessible. Observations were made from the exterior, interior catwalk around the lower portion of the domes, and through the use of binoculars. Our observations were limited to the precast framing and glass cladding of the domes. The following is a summary of our significant observations:

Precast Framing

1. Mesh netting secured to the precast framing with cables was observed in the Show Dome (Figures 12 and 13). The netting was in the process of being installed in the Arid Dome.
2. A few areas of the precast framing were sound tested in the Arid Dome from the catwalk at the base of the dome. Sound testing was performed using a hammer to detect delaminated areas. No delaminations were detected at areas which were sound tested.
3. Concrete spalls had been removed at several embedded connections where the hub from the glass cladding is supported by the precast framing (Figures 14 and 15). The embedded plate was painted at the location of removed spalls.
4. Concrete spalls, previously removed, were observed within the body of the precast concrete member, exposing reinforcing steel at a few locations in the Arid Dome (Figures 16 and 17). The reinforcing steel appeared to have minimal concrete cover.
5. Missing grout was observed between precast members at a few locations (Figure 17).
6. Fine, transverse-oriented cracks spaced along the length of the precast members were observed at several locations (Figure 18). Cracks were typically highlighted by soiling and peeling paint.
7. Cracked and peeling paint was observed on most precast members (Figure 19).

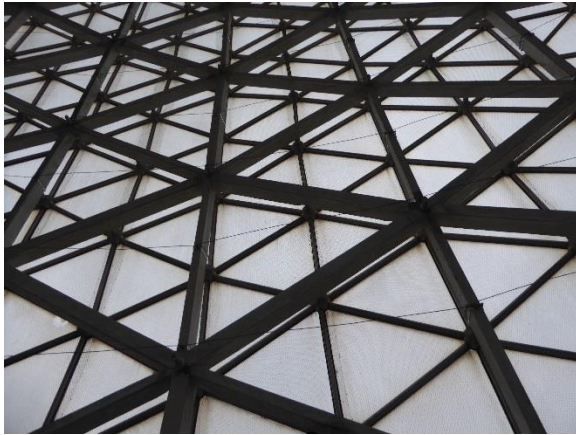


Figure 12. Netting and cables in Show Dome



Figure 13. Close-up of netting in Show Dome



Figure 14. Removed spall at connection location. Note: connection is painted with blue colored coating.

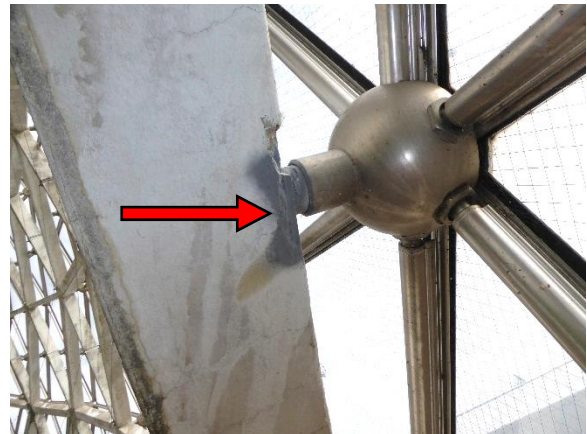


Figure 15. Removed spall at connection location. Note: connection is painted with blue colored coating.

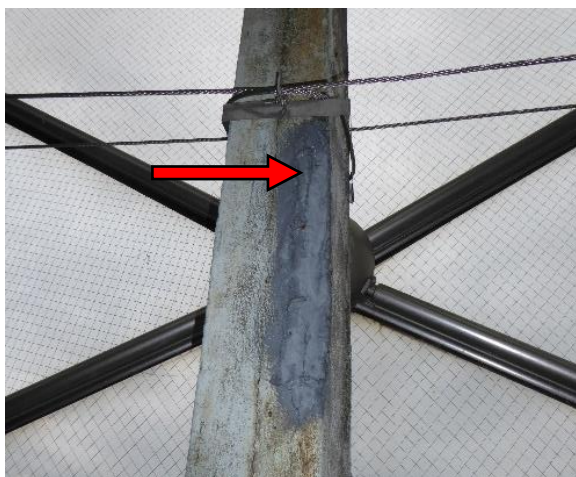


Figure 16. Removed spall within the body of the precast element. Note: concrete and reinforcing steel was painted with a blue colored coating.



Figure 17. Removed spall within the body of the precast element. Note missing grout between precast members.



Figure 18. Transverse cracks on precast member

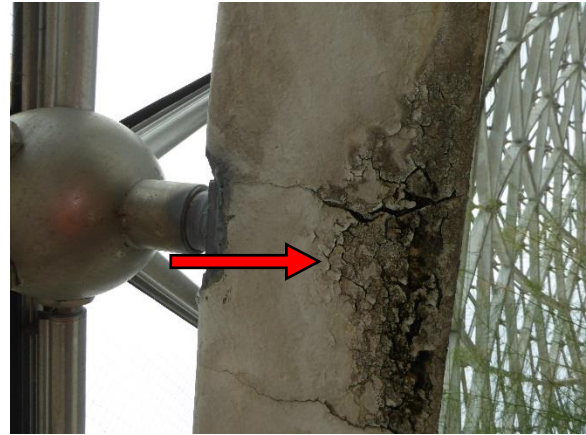


Figure 19. View of cracked and peeling coating on precast member

Glass Cladding

1. Cracked glass units were observed at several locations (Figures 20 and 21). Some of the cracked glass appears to be the result of impact.
2. The glazing material that separates the glass from the pressure caps has deteriorated over time. This is a likely source of water infiltration into the domes (Figure 22).
3. Sealant was installed around the hubs at several locations at the base of the domes (Figure 23).
4. Leakage was observed at approximately six locations in the Arid Dome at the connection of the hub to the downspout rafter. At locations where leaks were observed, the downspout rafter fitting had visible black material build-up, which seems to be an indicator of a leak location (Figure 24).



Figure 20. Cracked glass, likely from impact



Figure 21. Cracked glass



Figure 22. Glazing material at pressure cap on glass cladding



Figure 23. Sealant installed around hub of glass cladding

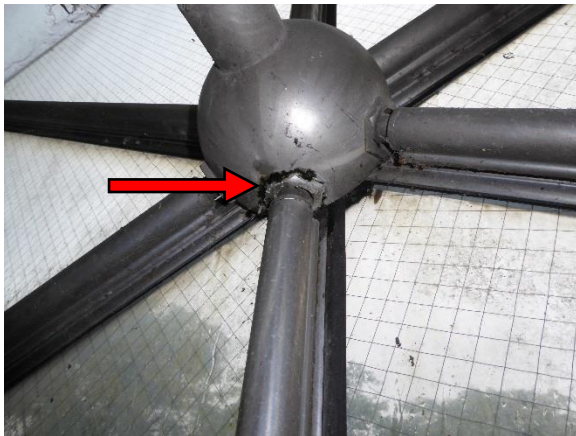


Figure 24. Black build-up on downspout rafter fitting at water leakage location

Discussion and Conclusions

Overall, the glass cladding and precast concrete have performed well considering that minimal maintenance and repairs have been completed on the domes. The primary issues are water leakage and spalling concrete at the embedded connections. Based on our observations and experience with similar structures, it is our opinion that the domes can be preserved and restored. Past repairs have not addressed water leakage into the domes.

Precast Framing

Based on our walk-through observations and review of previous GRAEF reports, the precast concrete framing appears to be in fair condition and consistent with long-term exposure to moisture and the environments within the domes. The primary issue is spalling concrete at the embedded connections, which appears to be the result of shallow concrete cover, corrosion of embedded plates, and cyclic temperature changes. Shallow concrete cover on the sides of the embedded plates makes the concrete susceptible to spalling as originally designed. The greatest amount of spalling was observed in the Desert Dome. We would expect the humidity level to be the least in the Desert Dome, which may indicate that the humidity level is not a significant factor in causing corrosion at embedded plates and subsequent concrete spalling.

The spalling hazard can be eliminated by removing the concrete cover at embedded plates. Installation of the netting system has mitigated concerns with spalling concrete. Corrosion at embedded plates will continue if ongoing water leakage is not resolved. We would anticipate that the amount of spalling concrete will decrease as water infiltration is minimized and a higher percentage of spalls are removed at connection plates. Concrete deterioration within the main body of the concrete member has only been an issue at a few locations with minimal concrete cover over reinforcing bars. However, continued exposure to moisture with a failed coating system can lead to additional deterioration of the concrete if not addressed.

The cracks observed on precast members are not an indication of any structural deficiency and appear to be the result of concrete shrinkage and stresses associated with normal structural behavior. In their current state, the cracks will continue to open and close with temperature change. The drying shrinkage in this concrete has mostly taken place and is not a factor to cause further cracking. The cracks should be protected from moisture. GRAEF reported cracks between precast members, and between the concrete base and precast members. We suspect that the cracks were observed in the coating system at the joint between precast members and between the concrete base and precast members. The joint should be sealed during the installation of the new coating system.

Glass Cladding

The primary issues with the cladding appears to be glass breakage and water infiltration. Some glass breakage appears to be related to impact while other locations may be related to thermal movements. The glass is wire reinforced. If broken, wire reinforced glass is not normally considered a falling hazard, since the wires engage the broken glass and inhibit broken glass pieces from falling. The glass framing has a drainage system that collects incidental water, either due to occasional rainwater leaks or internal condensation. GRAEF had indicated that water was observed sitting in the hub and not allowed to drain, which is likely the reason why water currently leaks out at the hub locations. In WJE's opinion, this condition is a result of the original design of the drainage system which set the opening in the downspout rafter slightly higher than the hub. We believe that this condition can be repaired (see our following Recommendations section).

GRAEF Repair Options

GRAEF has provided five restoration options and one replacement in-kind option with estimated costs ranging from \$14 to \$64 million. Option 1 retains most of historic fabric of the architecturally significant dome structures and maintains the existing appearance. The primary difference with Options 2 through 4 when compared to Option 1 is the use of coated insulating glass at a cost of approximately three to four times the repair cost of Option 1. GRAEF reported an energy savings of approximately \$110,000 per year with the coated insulating glass. The only cost difference between Options 1 and 2 is the replacement of all wired glass with coated insulating glass at an additional cost of \$24 million. Based on the reported energy savings, the coated insulating glass would pay for itself in over 200 years. Option 5 is a replacement option that removes the precast frame and installs a new self-supporting aluminum and glass clad dome structure. Option R is a replacement option that installs a new cladding system with coated insulating glass and rebuilds the concrete frame per the original construction.

Option 1 has a slightly higher cost related to glass maintenance. Maintenance costs for the precast framing are the same for Options 2 through 4. It is unclear how GRAEF developed the estimated life of the options or whether the life expectancy is referring to the repairs or the entire structure. With properly designed and installed repairs and regular maintenance, it is our opinion that the precast framing and glass repairs described in GRAEF's Option 1 will extend the useful life of the domes for many years. If water leakage is addressed and concrete repairs are completed, we would not expect concrete repairs would be needed for

ten to fifteen years or more. Obtaining current information on the concrete carbonation depth and corrosion potential of embedded reinforcing steel in precast framing would assist with more closely predicting anticipated future repair cycles. With continued future maintenance related to water leakage, we anticipate that concrete repairs would be minimal in future once spalling at all embedded connections is addressed.

GRAEF's Option 1 seems to be the most viable option, with the following considerations for enhancing the repair option:

- We recommend that the following characteristics be considered with the selection of a coating system: concrete carbonation protection, waterproofing, and aesthetics. The recommended coating systems by GRAEF for the precast concrete include an epoxy system and a stain. The stain will not be able to bridge cracks in the concrete and we do not recommend that a stain be installed. We recommend that further research be performed by GRAEF to understand the crack bridging capabilities of the proposed epoxy system. An epoxy system may fade and degrade slowly due to ultraviolet exposure, but could be beneficial to seal the concrete from oxygen depending on future corrosion potential due to the existing concrete carbonation depth and operating environment. A breathable acrylic or acrylic elastomeric coating could also be considered for the precast concrete members. An elastomeric coating will provide good crack bridging capabilities, but may not bond well in a humid or damp environment. A different coating system could be considered for each dome depending on the interior environment. Surface preparation and removal of the existing coating system may prove very difficult due to access and protection. Therefore, we recommend trial installations, bond testing, and evaluation of different coating systems and surface preparation techniques.
- The wire mesh could be removed after the repairs are completed to address water infiltration and spalling at embedded plates. Removing the wire mesh would require regular inspections and maintenance repairs to be completed as necessary. However, the mesh does provide a safety barrier against spalling concrete that has occurred in the domes.
- The wired glass can remain as is, unless it is broken; in which case it should be removed and replaced. Full replacement of the wired glass is not required for safety reasons. At locations where the wired glass is broken, WJE recommends replacement in-kind or with laminated glass. Laminated glass will have a change to the cladding's appearance.
- Based on our discussion with Rough Brothers Inc., an experienced greenhouse designer, they do not recommend replacing the glass with coated insulating glass because coated insulating glass is not beneficial for plant life. We agree with this assessment. In addition, the energy savings are slight when compared to the initial investment cost of coated insulating glass.
- For weather protection, WJE would normally recommend resealing the glass to aluminum joints around the dome. This is usually performed by a "wet seal" between the glass and the exterior aluminum (the pressure cap). In this case, however, the edges of the existing pressure caps are thin. Obtaining an adequate wet seal joint between the pressure cap and glass would be difficult. As an alternative, removing and replacing the pressure cap with a new redesigned pressure cap would allow for additional weather protection by: a) replacing the exterior glazing seals between the glass and the pressure cap with new glazing seals, and b) a thicker edge detail on the new pressure cap, which would allow a wet seal to supplement the new glazing seal. We believe that this redesign would largely resolve rain water leakage through the dome. We believe that this is a practical step for GRAEF to consider as an addition to their Option 1 repair.

Recommendations

We recommend prioritizing repairs that reduce water leakage into the domes. If water leakage into the domes is addressed, repairs to the concrete could be delayed if phasing the repair work is desired for economic or other reasons, since a safety mesh is currently installed. Phasing the work would increase the overall cost of the repair project. Laboratory analysis of the concrete should be performed to better

understand the characteristics of the precast related to concrete carbonation depth and internal humidity of the concrete. The additional information will be useful for understanding anticipated long-term deterioration and developing repairs. Monitoring of concrete debris in the netting should also be performed. Repairs could be implemented to significantly reduce water infiltration and restore the precast framing. The following repair recommendations should be considered to provide a long-term repair to the precast framing and glass cladding.

Precast Framing

1. Remove delaminated concrete at embedded plates, and clean and paint the plates. Proactively removing potential spalls at connection plates could be performed, but may not be necessary if the netting remains in place. If removing the netting is desirable, we recommend proactively removing potential spalls at embedded connections.
2. Repair concrete spalls with exposed reinforcing steel within the body of the precast member.
3. Repair deteriorated areas of grout.
4. Clean and paint the concrete with a coating system capable of bridging over cracks. Some cracks and joints may need to be stripe coated or sealed prior to the coating installation.

Glass Cladding

1. Replace existing cracked and broken wired glass in kind, or with laminated glass. Modifications in the glass replacement design could be implemented based on the findings from further investigation and mock-up repairs.
2. Remove and replace all pressure caps and wet seal joints (Figure 25).
3. Clean hubs and install self-leveling sealant at leading hubs (Figure 26).

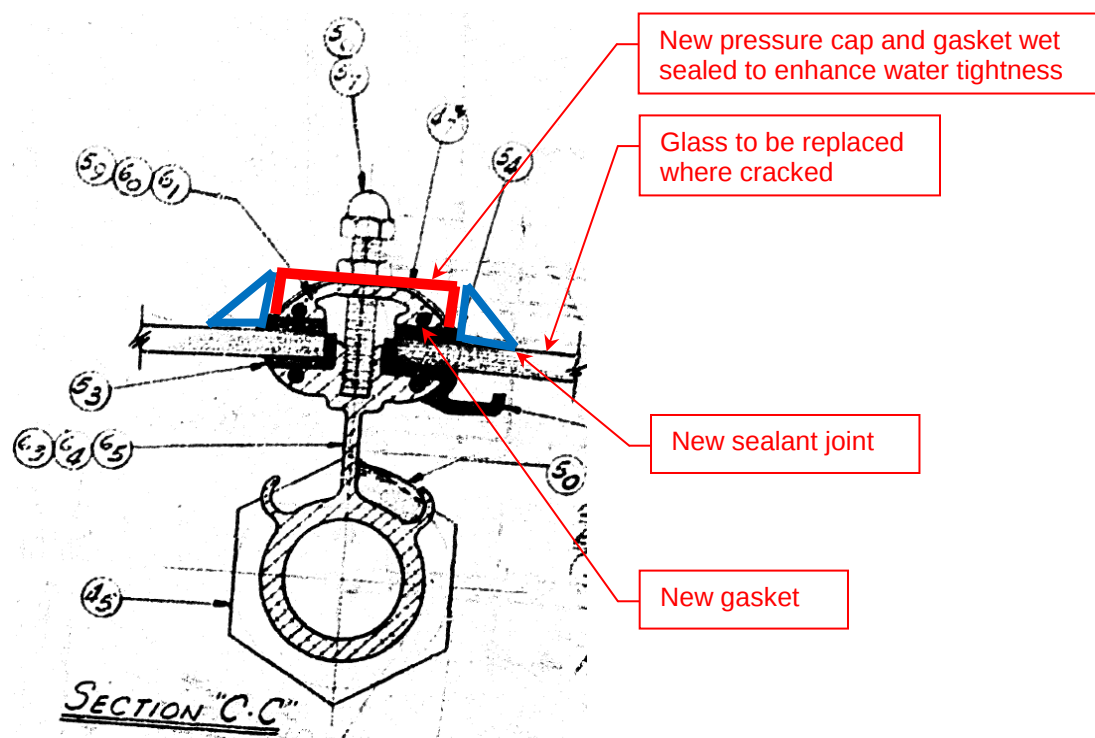


Figure 25. Section through glass and aluminum frame showing conceptual pressure cap repair for consideration

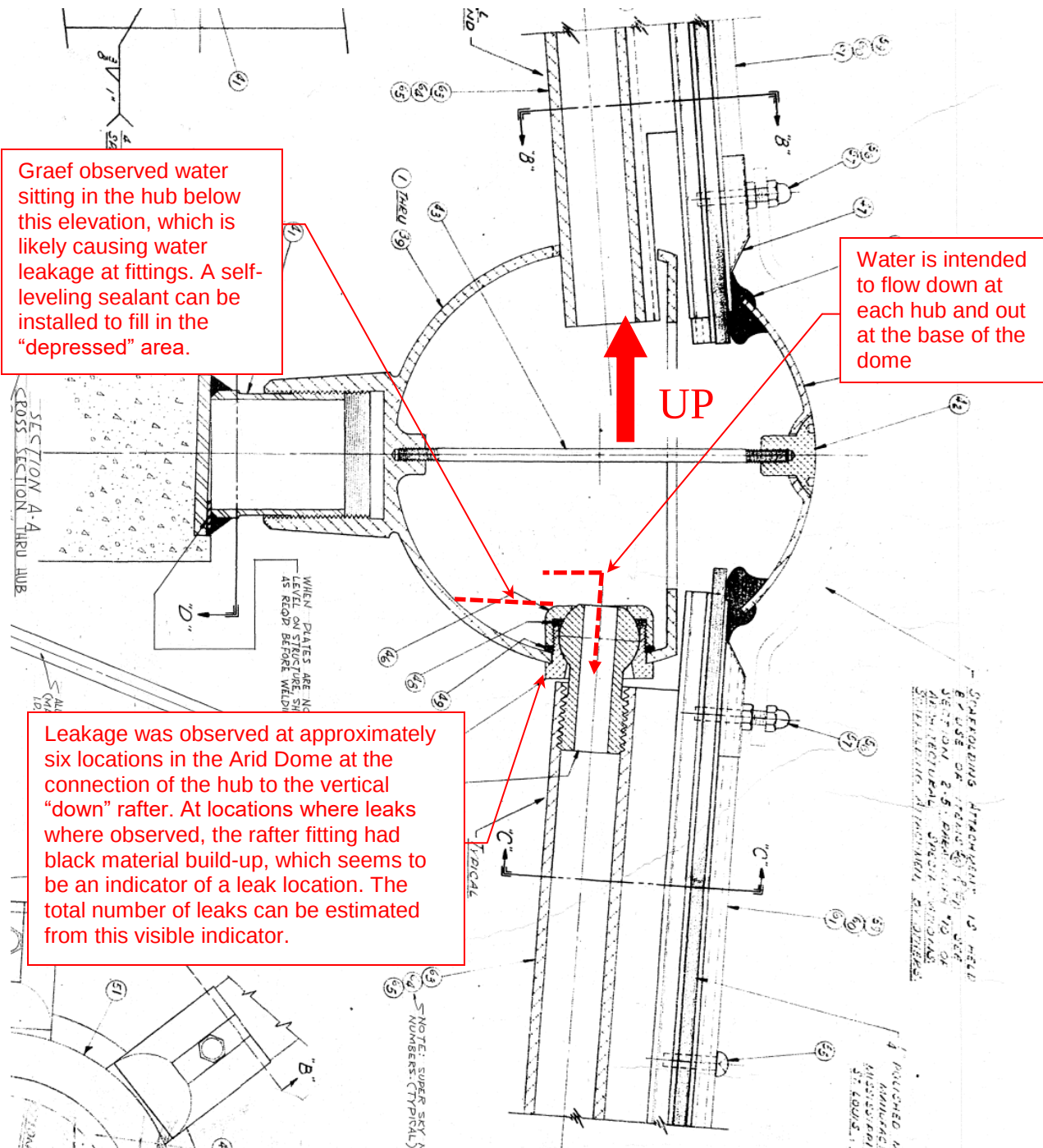


Figure 26. Conceptual hub repair

COST ESTIMATE

The costs provided are based upon our limited observations, review of GRAEF reports, assistance from Berglund (an experienced restoration contractor), and our previous experience with similar projects. The following is our opinion of probable costs, or “ballpark” costs, for repairing the precast framing and glass cladding to address the conditions described above.

1. Exterior access (scaffolding)	\$ 800,000
2. Remove concrete cover at connection plates; clean and paint connections	\$ 700,000
3. Repair concrete within the body of precast members	\$ 100,000
4. Repair deteriorated areas of grout	\$ 50,000
5. Install coating system on precast including sealant work allowance	\$ 550,000
6. Replace cracked and broken glass	\$ 500,000
7. Remove and replace pressure caps and wet seal joints	\$1,200,000
8. Clean hubs and install self-leveling sealant at leading hubs	\$ 300,000
9. Construction Escalation	\$ 200,000
10. General Conditions	\$ 400,000
11. Engineering	\$ 600,000
12. Contractor Fees	\$ 300,000
Total:	\$5,700,000 (each dome)
Total for three (3) domes:	\$17.1 Million

We have included the same percentages of subtotal fees as GRAEF for construction escalation, general conditions, engineering, and contractor fees. In the above cost estimate, we have excluded the following items included in the GRAEF cost estimate: vegetation protection, HVAC work, installing flashing at base, replacing damaged screens, and cleaning all wire glass.

If we include vegetation protection, HVAC work, installing flashing at base, replacing damaged screens, and cleaning all wire glass using the GRAEF cost estimates for these items, our estimated cost to repair the all three domes is approximately \$18.6 million, which is greater than GRAEF's estimate of approximately \$14.0 million for a similar scope of repair items as outlined in GRAEF Option 1. The primary difference in the higher cost is related to replacing all the pressure caps on each dome, which we believe will provide better weather protection, increase the service life of the domes, and provide a long-term repair.

Closing

The Mitchell Park Horticultural Conservatory Domes are unique, architecturally significant structures that have performed well during their first fifty-eight years of service life and can be preserved. The condition of the precast concrete framing and glass cladding is repairable, and replacement of these systems is not necessary at this time.

We recommend performing trial installation of the recommended repairs and evaluation prior to implementation on a wide basis. Often adjustments must be made to the scope of work, repairs, or the procedures to improve constructability of the repair, as well as accommodate unanticipated field conditions. Trial repairs also provide an opportunity to evaluate the performance of the repairs on a limited basis to evaluate their effectiveness in correcting the observed deficiencies.

It should be understood that a peer review with limited observations is not an investigation, thereby limiting the potential to uncover all ailments of the precast concrete or glass cladding. Likewise, WJE must rely on information provided by others. Also, we have not performed any work related to code review, ADA requirements, energy analysis, mechanical work, or other items not related to the precast concrete or glass cladding.

APPENDIX A - SUMMARY OF GRAEF REPORTS

1994 GRAEF REPORT

Background (reported by GAS)

1. Construction of the domes was completed in 1965. The total cost of the original construction was \$4.2 million.
2. The domes were designed using concepts which advanced the state-of-the-art construction of conservatories. Ideas developed from the construction of these domes have been studied and utilized on other projects throughout the county. They are unique structures that must be maintained if future generations are to enjoy them.
3. According to the Milwaukee County records, the domes have required very little annual maintenance. The domes have performed satisfactorily for thirty years, but are now showing signs of age.
4. The 1994 study of the domes was limited to the three domes above the level of the concrete foundation wall.

Precast Framing (reported by GAS)

1. A pattern of cracks appears in each of the domes. The cracks typically appear where two separate pieces were connected during construction, and between the concrete foundation walls and precast framing members. The cracks, although unsightly, appear to be only superficial in nature.
2. An average of twelve small concrete spalls were observed per dome. The spalls typically occurred at the embedded steel plate due to corrosion where the aluminum hub assembly is attached to the concrete frame.
3. One failed connection was observed at the west side of the Show Dome. GAS estimated that this condition may occur at six locations.
4. Half-cell testing was performed to determine whether there is active corrosion occurring in the reinforcing steel in the Tropical Dome and Show Dome. The testing indicated that there is a greater than 90 percent chance that no active corrosion is occurring at the tested locations.
5. Currently, the concrete appears to be in good condition based on the testing performed, but without adequate protection the concrete can deteriorate, causing significant structural problems in the future.
6. The concrete frame was originally painted with two coats of epoxy paint. The paint was specified to have a life expectancy of ten to fifteen years. The paint has been in service for approximately thirty years and is chalking and peeling. The majority of the peeling was observed in the lower areas of the Tropical Dome, which has the highest humidity. The paint protects the concrete and should be repaired to maintain the integrity of the structural frame.
7. The original specifications included in Appendix D specify a minimum compressive strength of 5,000 psi for precast concrete, and the reinforcing steel is specified as ASTM A15, which has a yield strength of 40 ksi for intermediate grade (not reported by GAS).

Glass Cladding (reported by GAS)

1. Each dome has approximately 3,150 pieces of 1/4 inch thick wire glass. Approximately 200 broken pieces of glass were observed in each dome, or about 7 percent of the total glass in a dome.
2. The majority of glass breakage in the upper one-third of each dome is thought to be caused by the brittle nature of 1/4 inch wire glass. Most of this type of breakage is believed to have occurred during the first few years of the domes' existence. The breakage in the lower two-thirds is a combination of the brittle nature of the glass and vandalism. Some breakage may have been caused by the shifting of the aluminum frame. Some breakage may have been caused when a cart was used as a platform for the window washers to clean the exterior of the glass. A small number of glass lites have been replaced or repaired.
3. The aluminum frame of the cladding system has an internal drainage system to channel moisture and is drained at the lowest hub, which is open and drips at doorways. Issues with the base flashing were also reported.

4. A total of thirteen of 5,500 hub caps were removed. Debris and water was observed in the hubs. In the Tropical Dome, the majority of the locations had so much debris that the vertical drain pipe was clogged. Five missing hub covers were also observed.
5. The steel in the apex appears to be in good condition in the Arid Dome, with some peeling paint exposing the primer.
6. The original specifications included in Appendix D specify that extruded aluminum rafters be designed for a snow load of 30 pounds per square foot (psf) and a wind load of 20 psf (not reported by GAS).

Recommendations and Options (reported by GAS)

1. To eliminate the cracks, the areas should be routed and sealed.
2. At concrete spalls, recommended repairs include cleaning and painting the embedded plate with no patching of the spalled concrete. Patching with grout is not recommended since the grout may shrink and crack, or fall off, causing further problems.
3. Two painting options were evaluated, including repainting the entire concrete frame and steel apex or repainting only the lower section of the concrete frame.
4. All hub interiors should be cleaned of debris and excess water removed during the reglazing process. The connection between the lower vertical pipe and the hub could be tightened at some locations during reglazing to compress the neoprene seals. The water at low points needs to be redirected to eliminate dripping at doorways.
5. The cost to repair hub attachments, drainage above doors, base flashing, and concrete was estimated to be between \$258k and \$528k depending on the painting option chosen. Painting costs were provided by three paint contractors.
6. Five levels of glazing replacement were evaluated:
 - Option 1 - Minimal replacement at lites that leak or have holes, which is estimated to be 300 lites for all domes (\$900k to \$920k)
 - Option 2 - Replacement of all cracked or broken lites, estimated to be 600 lites for all domes (\$1.75 to \$1.90 million)
 - Option 3 - Replacement of all lites in the upper one-third of the dome, estimated to be 3000 lites for all domes (\$4.65 to \$4.85 million)
 - Option 4 - Replacement of all cracked or broken lites with selected lites around the base where vandalism is a major concern, estimated to be 880 lites for all three domes (\$2.20 to \$2.26 million)
 - Option 5 - Total reglazing of all three domes (\$10.0 to \$10.5 million)
 - Super Sky was retained by GAS as a glazing consultant and assisted with the cost estimate.
 - As the glazing is replaced, the gasket material and seals could be replaced with new silicone based gasket material and silicone sealant.
 - Three glazing options suitable for replacement were researched: two laminated pieces of 3/16 inch clear heat-strengthened glass, two laminated pieces of 3/16 inch clear heat-strengthened glass with a Low-E coating and thicker interlayer, and 3/8 inch polycarbonate material for areas where vandalism is a concern.
 - The replacement glazing evaluated uses a 3/8 inch thick material, and the existing glazing system can accommodate the small difference in glazing material thickness.
 - Coated insulating glass is significantly thicker and heavier than the existing glass. Its use would require modifications to the glazing system. Coated insulating glass is a more expensive glazing project.
 - 1/4 inch clear wire-glass was not evaluated as an option, although still available, because it is not the state-of-the-art in glazing material. It is also a brittle glazing material and its production is limited. Appearance differences between clear glazing and the existing wire glass were deemed by Conservatory Management to be insignificant.

- A more energy-efficient glazing system should result in reduced annual gas costs. The gas service currently has an annual cost of approximately \$125,000.
- 7. A minimum maintenance repair program was recommended to protect the structural integrity of the domes within the next two or three years. The cost of this repair program was \$1.14 million.

2004 Asset Report

1. The current replacement cost was listed as \$37.6 million for the domes.

2008 GRAEF Report

Background (reported by GAS)

1. Limited repairs of glass panels (ten to twenty) were completed in the first forty years of service because of access difficulty and high costs.
2. GAS performed a condition study of the domes in 1993 and 1994. Broken and/or leaking glass, missing hub caps, and a poorly functioning drainage system was reported. The report also indicated that the concrete frame was in good condition; however, the paint was peeling and isolated areas of deterioration were present.
3. Repair work was completed over three phases from 1996 to 1998 including glass and gasket replacement, sealant repairs, hub cleaning, and minor concrete repairs.
4. The 2008 study of the domes was limited to the Show Dome.

Precast Framing (reported by GAS)

1. The concrete frame was reported to be in fair condition with paint that is fading and peeling, and isolated areas of concrete cracking and deterioration in the executive summary. The report later states that the concrete appears to be in good condition.
2. The same pattern of cracks was reported as the 1994 GRAEF Report. The cracks were reported to be a result of concrete shrinkage.
3. Approximately twenty small concrete spalls were observed in the concrete frame of the Show Dome. The spalls typically occurred at the embedded steel plate due to corrosion where the aluminum hub assembly is attached the concrete frame, just as reported in the 1994 GRAEF report.
4. One failed connection was observed due to corrosion. The same condition was observed in 1995 and a repair detail was prepared by GAS at that time, but the repair was not completed.
5. The paint is fading, chalking, and peeling in the Show Dome, similar to the 1994 GRAEF report.
6. A structural analysis of the Show Dome was completed by developing a three dimensional model using loading requirements of current codes. The preliminary analysis showed that the Show Dome was adequate to support its dead load and current code required live loads.

Glass Cladding (reported by GAS)

1. The Show Dome was reported to have broken and leaking glass, faulty aluminum framing components, and a poorly functioning condensation drainage system. All of these issues have created extensive water dripping within the Show Dome.
2. The 1/4 inch thickness of the glass makes the glazing very susceptible to breakage as a result of thermal stresses, vandalism, and use of cleaning equipment, as reported in the 1994 GRAEF Report. Additional stresses may also be created by structural swaying during high winds. 396 total panes of glass were observed to be damaged, or 12.4 percent of the total.
3. Water testing on a limited area of the Show Dome revealed one dripping condition at a lower hub after two hours of testing, but no visible interior water leaks at gaskets or glass cracks.
4. The glass gasket system has “dried up” due to age and is more prone to water leakage.

5. The internal drainage system for the aluminum cladding frame was reviewed. Hub covers were easily removed, and approximately 1/2 inch of water was observed with black debris. Water can accumulate in the hubs due to their construction and not drain until reaching the height of the rafter connection components. The inner and outer rafter connection gaskets appear to have failed, allowing the stored water in each hub to slowly drip into the dome.

Recommendations and Options (reported by GAS)

1. At concrete spalls, recommended repairs included cleaning and painting the embedded plate with no patching of the spalled concrete, which is the same as the 1994 GRAEF report.
2. The concrete frame should be recoated after leakage problems are corrected and all damaged glass has been replaced.
3. Several Show Dome renovation options were developed:
 - Option 1 - Repair Existing Cladding and Concrete Frame (\$4 to \$6 million)
 - a. Replace all damaged glass with the same wire glass. Install new gaskets and sealant joint between glass and existing rafter cap.
 - b. Replace top side gaskets where not previously replaced with new sealant joint.
 - c. Clean and modify the drainage system. Includes cleaning debris, installing flowable sealant, and reinstalling hub covers with new gasket and sealant.
 - d. Clean, repair, and recoat concrete frame. Removal of the existing coating was recommended. Several coatings were reviewed and Pittgaud 95-245 Series (Polyamide Epoxy) by PPG Paints and Tnemec Conformal Stain 607 (Acrylic Polymer Stain) were recommended for consideration.
 - e. Clean all wire glass panels.
 - Option 2 - Replace Existing Glass and Repair Concrete Frame (\$15 to \$18 million)
 - a. Replaces all glass with coated insulating glass. The use of coated insulating glass will drastically reduce the net energy needed to maintain inside temperatures. Insulating glazing units will provide better light transmittance resulting in faster plant growth from the higher light level. Coated insulating glass will also provide the needed resistance to damage from the outside.
 - b. The overall aesthetics of the domes will be significantly improved with looking from the street or from the gardens. Up close, the transparency of the glass wall will be better, allowing a better look inside from the outside.
 - Option 3 - Replace Existing Cladding and Repair Concrete Frame (\$8 to \$10 million)
 - a. Remove existing glass cladding and install new aluminum framing and glass cladding system.
 - b. The new glass cladding system would have coated insulating glass panels.
 - Option 4 - Replace Existing Cladding (self-supporting) and Repair Concrete Frame (\$10 to \$13 million)
 - a. Remove existing glass cladding and install new self-supporting aluminum framing and glass cladding system that is not connected to the existing concrete frame.
 - b. The new glass cladding system would have coated insulating glass panels.
 - Option 5 - Replace Existing Cladding and Remove Concrete Frame. (\$8.5 to \$10.5 million)
 - a. Remove existing glass cladding and concrete frame and install new self-supporting aluminum framing and glass cladding system.
 - b. The new glass cladding system would have coated insulating glass panels.
4. Options 1, 2, 3, and 4 maintain the existing appearance and shape of the Show Dome.
5. Options 2, 3, 4, and 5 would have insulating glazing which would significantly reduce the facility's energy usage.
6. Options 3, 4, and 5 would have a new aluminum cladding framing system, thus eliminating the shortfalls of the existing system.

7. Option 2 results in an approximate energy savings of \$55,000 to \$65,000 per year with coated insulating glass. Additional savings can be achieved with argon filled coated insulating glass in Option 3.
8. A life cycle cost analysis for the options was completed. The spreadsheet was not included in the report provided to WJE. Maintenance costs were included a five-year intervals for the glazing and at twenty-year intervals for the concrete.

2013 GRAEF Letter

Background (reported by GRAEF)

1. GRAEF performed a partial close-up inspection of the concrete frame inside the Tropical Dome and a very limited partial close-up inspection of the concrete frames in the Show Dome and the Arid Dome.
2. The immediate goal was to identify, document, and remove deteriorated concrete, in the limited study area, that could pose a hazard to employees and the general public.
3. Approximately 1,703 stainless steel posts (that are welded to embedded steel plates in the precast members) exist in each dome.

Precast Framing (reported by GRAEF)

1. Numerous delaminations were minor and the concrete pieces were still firmly attached to the concrete beams, so these concrete pieces were not removed.
2. The concrete spalls that were removed in the Show Dome and Arid Dome were generally firmly attached but were tested and removed, using significant force, to verify that condition.
3. The delaminations and spalls are generally occurring adjacent to the locations where the aluminum glazing supports are connected to the concrete frame.
4. Tropical Dome:
 - 455 post locations were reviewed close-up (27 percent of all post locations)
 - 48 post locations had delaminations (10 percent of total reviewed)
 - 131 post locations had spalls (29 percent of total reviewed; 100 removed by GRAEF Engineers)
5. Show Dome:
 - 105 post locations were reviewed close-up (6 percent of all post locations)
 - 32 post locations had delaminations (35 percent of total reviewed)
 - 5 post locations had spalls (5 percent of total reviewed; 5 removed by GRAEF Engineers)
6. Arid Dome:
 - 29 post locations were reviewed close-up (2 percent of all post locations)
 - 22 post locations had delaminations (76 percent of total reviewed)
 - 2 post locations had spalls (7 percent of total reviewed; 2 removed by GRAEF Engineers)
7. Based on these results, GRAEF recommends that additional inspections be completed in all domes to determine the extent and types of repairs required to make the domes safe for employee and visitor occupancy.

2015 GRAEF Report

Background (reported by GRAEF)

1. Milwaukee County Parks staff reported concrete debris ranging in size from coin to golf ball proportions found on the ground of the dome, including paved paths frequented by public patrons.
2. Full close-up inspections of each dome were performed in 2013 and 2014.
3. The focus of the inspections was the condition of the concrete structure, particularly where it interacts with the glazing system.
4. The repairs performed during this project primarily addressed immediate falling hazards that were present at the time of the inspections. The repairs performed during this project do not constitute final repairs or a long-term maintenance plan for the structures.

Precast Framing (reported by GRAEF)

1. The vast majority of the concrete debris originated from spalls at embedded plates. Light corrosion at these plates puts pressure on the concrete, causing pieces to fall to the ground. During this project, inspectors knocked off loose and cracked concrete off these locations. The plates were then painted with a zinc primer to slow additional corrosion.
2. Less commonly observed issues:
 - Misaligned embedded plates and glazing connections were reinforced with stainless steel clamps.
 - Eroded or deteriorated grout joints between the precast members were hammer tapped, and loose grout was removed. Sections were regouted during the repair project.
 - Where spalled concrete exposed steel reinforcing bars, either the rebar was painted with a zinc primer (in areas of small spalls) or the concrete was patched (in areas of structurally significant spalls).
 - Where the concrete was being eroded or steel connections were being saturated by water drips from the glazing system, plastic gutter-type pieces were installed to redirect the water off the structural frame.
3. Inspectors noted the majority of loose or delaminated concrete occurring between the edges of plates and the edge of the concrete member embedded within 4-inch wide concrete members, with many delaminations also occurring in 6-inch wide members. The concrete was not generally spalling when the edge of the plate was not near the edge of the concrete member. The embedded steel plate, therefore, makes all narrow precast members susceptible to spalling as a result of corrosion. The narrowest concrete members tend to spall first.
4. The thin pieces of concrete on the sides of the plates are very susceptible to spalling. Concrete shrinks as it cures, causing the concrete to crack at its weakest points. This detail of thin sections of concrete with reentrant corners next to the plates is the weakest area of concrete. In many locations, it is likely that the concrete weakened in these areas during curing. Then, though these plates exhibit only freckled surface rust, the expansion caused by light corrosion generates enough force to spall the concrete that conceals the sides of the embedded plates. The weakened planes also allow for some areas to spall even without the presence of rust. Other explanations for spalling are possible; however, this reason was the most consistent account.
5. Concrete Frame Evaluation Summary of Tropical Dome:
 - 1589 of 1685 hubs (post locations) were reviewed close-up (94.3 percent of all post locations)
 - 94 hubs were inaccessible at base (5.6 percent of total)
 - 606 locations with spalled concrete (38.1 percent of total reviewed)
 - 84 locations with spalled grout (5.3 percent of total reviewed)
 - 104 locations with exposed rebar (6.5 percent of total reviewed)
6. Concrete Frame Evaluation Summary of Desert Dome:
 - 1592 of 1688 hubs (post locations) were reviewed close-up (94.3 percent of all post locations)
 - 96 hubs were inaccessible at base (5.7 percent of total)
 - 835 locations with spalled concrete (52.4 percent of total reviewed)
 - 17 locations with spalled grout (1.1 percent of total reviewed)
 - 51 locations with exposed rebar (3.2 percent of total reviewed)
7. Concrete Frame Evaluation Summary of Show Dome:
 - 1601 of 1678 hubs (post locations) were reviewed close-up (95.4 percent of all post locations)
 - 77 hubs were inaccessible at base (4.6 percent of total)
 - 500 locations with spalled concrete (31.2 percent of total reviewed)
 - 50 locations with spalled grout (3.1 percent of total reviewed)
 - 2 locations with exposed rebar (0.1 percent of total reviewed)

Glass Cladding (reported by GRAEF)

1. During the course of the inspections, the connections of the aluminum framing cap and the concrete structure at the top of each dome were also inspected. Deteriorated and broken nuts were found in some of the connections between aluminum framing members. The nuts and bolts were replaced in that connection at all locations in all three domes.
2. Water wets the dome structure from several different sources, including:
 - Atmospheric humidity, resulting from watering plants and evaporation within the greenhouse
 - Leaks from holes in the wire-reinforced glass and surrounding gaskets of the glazing system
 - Clogged metal hubs that overflow with drips
3. Corrosion of embedded steel connection plates appears to be the main consequence of this moisture.

Recommendations and Discussion (reported by GRAEF)

1. Long-term preservation plans for the domes should consider repairing or replacing the glazing system, cleaning and repainting the concrete structure, and performing routine inspections (every two to three years) of the structure to monitor the progression of deterioration.
2. Because the majority of the water causing damage is coming from the glazing system, it is imperative that the glazing system be addressed if the buildings are to remain in operation and in a safe condition for the staff and visiting public.
3. Preservation of the primary concrete space frame structure is still possible, because no significant section loss of steel reinforcing or embedded plates was observed. In most cases, the concrete lost to spalling only functioned as cover for the embedded plates. The concrete that creates the structural frame remains intact. Because of the accelerated pace at which wet structures can deteriorate, provisions for future inspections and/or repairs should be made within the next two years. Future inspections, at arm's length, should be conducted at regular intervals, perhaps every two to three years, until repairs may justify longer periods between inspections.
4. Concrete will continue to fall as more deterioration occurs. It is not possible to reasonably determine when this will happen due to the number of factors involved, but it is certain to happen at some point.

May 2015 GRAEF Letter (reported by GRAEF)

1. A site observation was made at the Mitchell Park Domes to view a collection of fallen debris and discuss the material that was collected by Milwaukee County Parks personnel. A sample of the fallen debris was observed, with the largest pieces being roughly 1 inch in diameter by 1/2 inch thick. Some of the pieces were stained by soil and appeared to be from the sounding process during the investigation performed by GRAEF in 2013 and 2014. Other pieces appeared to have fractured recently because there was no staining evident.
2. The weather in the past few weeks has been fluctuating greatly, with temperatures in the 80s one day, followed the next day by freezing temperatures. The dome is made up of uninsulated glass, so the window frames and the concrete structure will expand and contract with changes in temperature. Direct sunlight will also heat up saturated concrete surfaces, causing expansion and loosening of concrete elements. The window frames are not air-tight, so some wind pressure can enter the dome and create air currents indoors. Likewise, strong winds can cause racking and slight horizontal movements of the dome structure that can dislodge loose concrete. These are all likely reasons why concrete debris on the dome floor has been observed this spring.
3. Therefore, it is our recommendation that the domes continue to be monitored. Discovery of segments of debris that are larger than a quarter should be logged by taking a photo and recording the location on a floor plan. If larger debris pieces are observed, then an action plan may need to be instituted to protect people and property inside the domes. It is advisable that both a short-term and long-term plan be developed that will prevent or capture falling debris. At this time, based on the evidence presented,

it does not appear that the dome structure presents an imminent threat or poses a danger to the general public or Milwaukee County Parks Department workers.

July 2015 GRAEF Letter

Background (reported by GAS)

1. The Milwaukee County Parks staff has found concrete debris in the planting beds in each of the domes since inspections were completed in 2014. Debris was not discovered on any of the pedestrian walkways.
2. In order to determine the source of the concrete and to search for any changes to the domes' conditions, a limited number of the structural elements of the Domes were inspected from aerial lifts on July 14, 15, and 17, 2015.

Precast Framing (reported by GAS)

1. During this partial inspection of the Domes, no evidence was found of new concrete spalls that would have occurred since the 2013-2014 inspections. At a few locations, inspectors knocked off loose and cracked concrete from the intersection of the glazing system and the structure, likely caused by continued corrosion of the embedded steel plates.
2. Overall, we found that the conditions were similar to the conditions at the completion of the 2013-2014 inspections. It does not appear that the discovered concrete debris is from new concrete spalls, at least in the area that we were able to examine. We believe that the discovered debris is most likely from concrete that was knocked loose during the 2013-2014 inspections.
3. Despite finding a lack of new concrete spalls, additional pieces of concrete that were cracked and could have fallen in the future were discovered during this inspection. This reinforces our opinion that the structures should be watched for additional spalled concrete. It is still likely that it will occur again in the future. It is imperative that the moisture issues related to the glazing system at the Domes be addressed if the buildings are to remain in operation and in a safe condition for the staff and visiting public. In the meantime, the county should continue to watch the structure for additional concrete spalls.

February 2016 GRAEF Letter

Background (reported by GAS)

1. A visual assessment of the Desert Dome was performed from the ground and ladders.
2. The purpose of this assessment was to attempt to find the origin of the piece of concrete that was found on the catwalk on Monday, January 25, 2015.

Precast Framing (reported by GAS)

1. Within the height limit, the location where the piece came was not found. GRAEF did not see any concrete spalls that had occurred since the last inspections in 2014 and 2015.
2. Based on the appearance of the piece of concrete, we believe that it has come from the building structure rather than from shotcrete stonework or from mortar between the precast pieces. However, the shape of the piece and the lack of paint on any of the surfaces greatly limits the locations where it could have come from on the Dome's framework. It is possible that the piece came from another portion of the structure such as one of the entries, or the base of the building below the windows. However, no specific locations were found that matched the piece in those areas either.
3. GRAEF suggested that the concrete debris be lab tested to determine whether it came from the structure or another location.
4. Overall in the areas that we were able to reach from ladders, we did not see any substantial change in the condition of the concrete structure.

5. The Domes are old structures that are showing the effects of their age. They will continue to deteriorate unless major renovations are completed. Until that work is performed, or other long-term steps are taken to address the conditions at the Domes, we feel that the most cost-effective way to reduce the possibility of injury from falling debris is to install protective netting in the areas where concrete pieces and chips have been known to originate.

February 2016 Presentation (reported by Milwaukee County)

1. \$1.0 million in inspection and repair funds was approved by the County Board in 2014 and 2015.
2. Renovation costs and options from 2008 GRAEF Report were reviewed.
3. Current actions include spalling protection to reopen the Show Dome by the end of April.
4. Protective options were reviewed, including wire mesh and UV resistant wrap.
5. Next actions include spalling protection to reopen the Arid and Tropical Domes.

March 2016 Presentation (reported by Milwaukee County)

1. 2015 GRAEF Report findings were reviewed.
2. A recent timeline of concrete debris that has been discovered was reviewed.
3. A netting mock-up meeting was held in January 2016.
4. The mesh option is significantly less cost than the UV resistant wrap option.
5. The mesh netting cost is \$266k for 1/2-inch stainless steel hex mesh in the Show Dome.

May 2016 Presentation (reported by Milwaukee County)

1. The Show Dome netting was installed. Show Dome to open April 30.
2. Next actions include spalling protection to reopen the Arid and Tropical Domes.

2016 GRAEF Report

Background (reported by GRAEF)

1. The purpose of this 2016 Report Update is to inform Milwaukee County and concerned stakeholders about the changes that have occurred to the domes over the eight years since the 2008 GRAEF Report. It is intended that the information provided here will help Milwaukee County and concerned stakeholders to make an informed recommendation for the future of the Mitchell Park Horticultural Conservatory.
2. In addition to the previous five repair options, Option R: Replacement (in kind) on Existing Foundation per original construction was included.
3. Numerous projects, including major maintenance and capital improvement projects, have been conducted at the Mitchell Park Domes over the fifty years since original construction. Major maintenance projects have included the replacement of over 1,000 panes of cracked or broken panes of glass on all three domes.
4. In 2016, a stainless steel mesh was installed on the underside of the concrete frame of all three domes to protect the public from falling pieces of concrete. In the spring of 2016, a stainless steel mesh was installed (to catch falling pieces of concrete) on the underside of the Show Dome's concrete frame. The project cost was \$260k. A stainless steel mesh was also installed in the Desert and Tropical Domes, completed in October 2016. The total estimated cost for these two domes is currently estimated to be just under \$1 million.
5. The glass, aluminum cladding, and concrete frame are generally in fair condition from a strength standpoint; however, deterioration of all these elements has affected the operational and functional efficiency of the facility (e.g. damage to plants, energy costs). Space utilization is significantly

inadequate to support the horticultural and educational mission of the facility. Numerous code compliance issues as well as shortcomings in meeting ADA requirements should be addressed.

6. Cost estimates in the report include current Code and ADA requirement costs and 2019 project construction timelines. Middleton Consulting and Contracting, Masonry Restoration Inc., and Super Sky, assisted GRAEF with cost estimates.
7. An energy study indicates that the Mitchell Park Domes would realize a savings of approximately \$110,000 per year with the coated insulating glass. This savings assumes no changes to the current HVAC system.

Options (reported by GRAEF)

1. Option 1 - Repair Existing Cladding and Concrete Frame
1. Option 2 - Replace Existing Glass and Repair Concrete Frame
2. Option 3 - Replace Existing Cladding and Repair Concrete Frame
3. Option 4 - Replace Existing Cladding (self-supporting) and Repair Concrete Frame
4. Option 5 - Replace Existing Cladding and Remove Concrete Frame
5. Option R - Replacement (in kind) on Existing Foundation