August 17, 2017

Mr. Brad Holm, Esquire
City Attorney
City of Phoenix Law Department
200 W. Washington St - Suite 1300
Phoenix, AZ  85003

PRELIMINARY REPORT

Re: Roofing and Fire Sprinkler System Damage Assessment
Burton Barr Library
Phoenix, AZ
WJE Project No. 2017.4493

Dear Mr. Holm:

On July 24 and 25, 2017, WJE representatives John Duntemann, Carl Baldassarra, Michael Aaron, and Richard Koziol performed a site investigation to assess damage that occurred at the Burton Barr Library in Phoenix, Arizona due to a reported storm and high winds on July 15, 2017. The focus of our investigation was primarily related to the roof and fire sprinkler system. We were assisted by Star Roofing, who provided labor to make and repair five exploratory openings in the roofing system. RCI Inc., the company that maintains the sprinkler systems, also assisted. In attendance to witness the exploratory openings were: representatives of DWL Architects; Will Bruder Architects; consultants for the insurer, Rimkus Consulting Group and McLaren’s (insurance adjuster); and the City of Phoenix. The purpose of the openings was to examine and document concealed conditions within the ballasted roofing assembly and to review the sprinkler system piping. This site visit followed an initial site visit performed by WJE on July 20 and 21, 2017.

FIRE PROTECTION

Background

Automatic sprinkler protection is widely recognized as providing superior protection for life safety and property. Each automatic sprinkler has a fusible element activated by heat and operates individually in the vicinity of a fire, releasing water from piping in a prescribed amount based on the hazard. Automatic sprinklers are manufactured to meet product standards published by Underwriters Laboratories (UL) within stringent tolerances. According to the sprinkler industry, the probability of a spurious sprinkler operation, i.e., operation of a sprinkler without any external cause, is one in 16 million.
System Types

Various types of fire sprinkler systems are available depending on building conditions and owner preferences. These include:

1. *Wet pipe* sprinkler systems are by far the most common type. They normally have water in the piping at all times. This allows water to be immediately discharged onto the fire by activated sprinklers. Wet systems are typically used throughout buildings where piping is not subject to freezing conditions. Wet systems are the simplest and most reliable type of fire sprinkler system, requiring the least maintenance.

2. *Dry pipe* sprinkler systems are normally used for unheated buildings in freezing climates. Dry pipe sprinkler systems normally have compressed air in the piping. If one or more individual sprinklers are activated by heat due to a fire, the air pressure in the piping is released until such time as a dry pipe valve, normally held closed by the air pressure, is activated, allowing water to flow into the piping to discharge through the open sprinklers. This arrangement causes a small delay in water being discharged, but is a necessary compromise for piping in buildings exposed to freezing temperatures.

3. *Preaction* sprinkler systems are most commonly used in areas that are particularly sensitive to water damage, such as large computer rooms or telecommunications facilities. A preaction system normally has compressed air in the piping with the water held back by an automatic operating preaction valve. Not to be confused with dry pipe valves, however, preaction valves are activated by signals from a separate fire detection system. When called upon by fire detection signal(s) from the fire alarm system, the preaction valve opens to fill the piping with water. No water is discharged unless sprinkler(s) have also been activated by heat in a conventional manner.

Preaction systems ordinarily provide more protection from inadvertent sprinkler system operation. Preaction systems require the activation of two separate systems for water to be discharged: first, the detection system, second, the operation of a heat-activated sprinkler. Operation of a sprinkler alone will only cause the air to be released from the piping, but no water will be admitted to the piping downstream from the preaction valve. Similarly, operation of the detection system alone will only cause water to enter the piping, but no water will be released unless sprinklers are also activated. Since the preaction piping is normally dry, there is a reduced danger of water damage from accidental discharge of a sprinkler or a leaking pipe.

However, one of the disadvantages of preaction sprinkler systems is that they are more complex than wet pipe sprinkler systems. This complexity occurs because the preaction valve, a mechanical device, must operate in response to a fire detection system to fill the sprinkler system with water, by a mechanical-electrical interface. This operation makes preaction systems inherently less reliable than wet pipe sprinkler systems in comparable circumstances. Preaction systems also require more maintenance than wet pipe systems.
Importantly, the compressed air in preaction systems tends to cause more corrosion of the piping. Water vapor and oxygen are normally present in the piping, and new oxygen and water vapor are introduced as the air compressor makes up for normal compressed air leakage. New water and oxygen are also introduced at the time of semi-annual system tests. Corrosion in preaction systems can be mitigated by the use of compressed nitrogen rather than compressed air. Although there is an increased cost for nitrogen systems in lieu of air, this alternative has gained more proponents recently.

In wet pipe sprinkler systems, the water is normally stagnant in most of the piping. The dissolved oxygen in the water causes pipe corrosion. However, this corrosion slows as the available oxygen is consumed and reduced to low concentrations. New oxygen is introduced in a small part of the piping when sprinkler system flow switches are tested semi-annually, or when the systems are flushed.

In the case of preaction systems and dry systems, it is also important that the piping is drainable to reduce corrosion. Further, it is preferred that sprinkler piping be routed in concealed spaces above ceilings (where ceilings exist) or exposed beneath open roof decks or ceilings. In that way, the piping is accessible for inspection, maintenance and repair. Embedding the sprinkler piping in an inaccessible manner within structural or architectural features is unusual and generally avoided except in circumstances where there are no practical alternatives.

**Current Fire Protection Practice**

Libraries employ a variety of fire protection strategies. Most recently constructed libraries include automatic fire suppression systems as part of a comprehensive fire protection program. In all but the smallest libraries, automatic sprinkler protection is required by the building code in new construction; the option remains to select the type of sprinkler system.

Currently, many libraries, including the Library of Congress of the United States in Washington, D.C., employ wet pipe sprinkler systems for most areas, other than for rare book collections or irreplaceable objects. The fire protection strategy for such rare collections includes fire-rated construction separations, e.g., walls, to protect the collections from fires originating in other parts of the building; smoke detection to provide early detection of a fire and notification to staff/fire department to take remedial action; and, special suppression systems, such as preaction sprinklers or a clean agent (gaseous) system, or a combination of these systems.

Wet pipe sprinkler protection is deemed sufficiently reliable to provide superior protection for life and property while also providing reasonable protection against accidental discharge of water. Burton Barr stakeholders should review its collections, the advantages and disadvantages of each type of sprinkler system, and select the appropriate system type for the Fifth Floor replacement. To aid in this process, WJE is assembling technical information about the various types of replacement sprinkler systems for consideration by the stakeholders.
WJE Observations

The Burton Barr Library is a five-story, noncombustible building which opened in 1995 and is considered a fully-sprinklered building, with the exception of the Rare Books room on the Fourth Floor. Wet systems protect the library’s First through Fourth Floors. Protection for the Fifth Floor consists of two preaction systems (Figure 1) protecting the stack area, connected to system risers at the east and west sides of the facility, and two wet pipe sprinkler systems (Figure 2) for back-of-house areas. The four sprinkler systems serving the Fifth Floor were not in service at the time of our site visits in July, 2017.

![Figure 1. Preaction Valve Serving One Half of the Fifth Floor Stack Area](image)
The Fifth Floor preaction system piping is embedded in the Burton Barr Library’s roof structure. The roofing assembly consists of a ballasted configuration utilizing lightweight interlocking precast concrete pavers, loose-laid ethylene propylene diene monomer (EPDM) membrane, polyisocyanurate rigid board insulation (8 inches thick, loose laid) and galvanized acoustical metal deck (7-1/2 inches deep) with fiberglass batt insulation within the deck flutes spaced on 12 inch centers. The Fifth Floor preaction system sprinkler system piping is positioned above the metal deck, within the lower layer of rigid board insulation, and rests in part on the metal deck. Sprinkler piping “drops” extends downward through the ribs of the metal deck to the pendent sprinklers which are positioned at the underside of the deck (Figure 3). The configuration and layout of the sprinkler system piping is concealed from observation, and only the sprinklers are exposed on the underside of the deck. This sprinkler piping installation above the roof and within the roof assembly is unusual.
On July 25, 2017, five openings were made in the roofing material to expose the sprinkler piping for observation. The sprinkler piping is steel with 4-inch diameter cross mains and 2-inch and smaller diameter branch line piping (Figure 4). Cross mains and branch lines are positioned in the same plane. The branch lines are connected to the cross mains with welded outlets. Cross main piping appears to be Schedule 10 black steel with grooved couplings. The branch line piping appears to be a combination of Allied Dynathread and Dynaflow piping. Starter pieces from the welded outlets are threaded, while the remainder of the branch line piping has grooved connections.
Five samples of sprinkler system piping, one from each opening in the roof covering, were removed for testing at an independent laboratory. We observed that some of the samples display significant corrosion.

**Incident**

WJE’s investigation of the July 15, 2017 loss is ongoing. Preliminary information revealed that some preaction sprinkler system piping serving the Fifth Floor was corroded. The air compressors for the preaction system piping were not operational, but the means for system activation (the smoke detection system and the heat-activated sprinklers) and the water supply to the preaction valves were in service.

The sequence of system operation on the date of the loss is being reviewed. At this time, it appears that the smoke detection system was actuated and, in turn, activated the preaction valve(s), allowing the water to enter the piping network, as designed. Part of preaction sprinkler system piping was charged with water and would have been available if a sprinkler was activated. However, due to the corrosion of a part of the piping, water leaked out of the west preaction system piping and entered the northwest part of the building through the roof above the Fifth Floor.

Although some sprinkler system piping on the Fifth Floor was corroded, the life safety of building occupants was not affected. The Fifth Floor area protected by the preaction systems is a large, high-ceiling space (Figure 3) which creates a substantial building volume. Even without the benefit of automatic sprinkler protection, the large building volume is capable of sustaining an uncontrolled fire for a time period that would allow occupants ample time and opportunity to reach an exit stairway. Other building fire safety features contribute to the level of safety of the building, including: noncombustible construction; smoke detection system; manual alarm stations, occupant notification devices; automatic notification to the fire department; a smoke exhaust system; a robust egress system, including areas of refuge with supplemental communication systems for use by disabled occupants; fire standpipe system; and operational sprinkler protection on Floors 1 through 4.
Design Considerations

The two preaction sprinkler systems protecting the Fifth Floor are not salvageable and must be replaced by newly-designed systems. Corrosion in the existing piping and the inaccessibility for inspection, maintenance and repair associated with the existing configuration make repairing the existing system an impractical option.

To facilitate future inspection, testing, and maintenance of the sprinkler system in accordance with local codes and nationally recognized standards, the piping for the new Fifth Floor automatic sprinkler systems should be installed below the roof deck. We believe the replacement system can be designed and installed in an aesthetic manner, maintaining the architectural fabric of the building. Significantly, the library’s architect expressed that he is in agreement in principle with the concept of installing the Fifth Floor sprinkler system piping below the roof deck.

The routing of the supply piping for the replacement sprinkler system for the Fifth Floor, whether wet pipe or preaction, must consider the roof slope such that the system piping can be drained for inspection and maintenance purposes. One concept of pipe routing is the installation of the piping below the deck, near the north-south walls of the stack area, supplying branch line piping in the east-west direction within the ribs of the deck (Figure 5). Sprinklers could be positioned to be flush with the bottom of the ribs to allow for the collection of heat to activate the sprinklers, unobstructed distribution of water, and minimum visual effect. The piping would be painted to match the color of the deck; the color of the sprinklers would also be coordinated. This, and other concepts, must be developed to enable the City to make a final selection.

All piping must be carefully installed to facilitate drainage. Other measures to reduce the effects of corrosion should be carefully considered once a selection of system type is determined. Care is also needed to provide proper structural support for the necessary pipe hangers. The details of design and installation remain to be developed.
Figure 5. Proposed Sprinkler Piping Option
ROOFING SYSTEM

Background

A general view of the roof is presented in Figure 6. The main roof area covers a plan dimension of 163 ft by 260 ft (42,380 square feet). The roof structure is sloped in a curved geometry, at an approximate slope of 1:12 toward internal drains at recessed low areas along the east and west sides of the main roof. The roofing assembly consists of a ballasted configuration utilizing the following materials from top to bottom: lightweight interlocking precast concrete pavers, loose-laid Ethylene Propylene Diene Monomer (EPDM) membrane, polyisocyanurate rigid board insulation (8 inches thick, loose laid) and galvanized acoustical metal deck (7-1/2 inches deep) with fiberglass batt insulation within the deck flutes.

The roofing system was damaged on the north end of the building by wind from a storm reported to have occurred on July 15, 2017. The preliminary wind data obtained from the National Weather Service indicates the maximum winds on July 15, 2017 occurred around 6 pm. The estimated wind speeds were between 40-50 mph at this time, and considerably less than the design wind speeds specified by Code at the time the library was built and the design wind speeds specified by current Code. The wind uplift damage resulted in displaced and detached precast concrete pavers and rigid insulation beneath the EPDM membrane. (See Figures 7 and 8.)
Figure 7. Displaced and Detached Precast Concrete Pavers at the North End of the Main Roof Area

Figure 8. View of Wind-damaged Area Looking Westward from the Northeast Corner
**WJE Observations**

Five exploratory openings were made in the roofing system to examine conditions concealed beneath the concrete pavers and EPDM membrane and to review and obtain samples of the sprinkler piping. The locations were numbered 1 through 5 and are shown on the roof plan drawing presented in Figure 9.

The paver ballasted EPDM roofing assembly appeared well-constructed from a water tightness perspective based on observations made at the five exploratory openings. The 60 mil EPDM membrane is loose laid over the rigid board insulation. Although the EPDM membrane appeared in relatively good condition for its age, it is approaching the end of its expected service life. Two layers of four inch thick polyisocyanurate board insulation totaling eight inches are loose-laid over the corrugated metal deck. The insulation board layers are laid with joints staggered. Significantly, the insulation was dry at each of the five exploratory openings.

The metal deck is a type referred to as an acoustic metal deck because it has sound attenuation features. The deck is made of interlocking sections of 18 gauge galvanized steel. The deck ribs are spaced on 12 inch centers. The deck is attached to the top of the structural steel tube purlins with puddle welds at each rib/flute and puddle welded at the bottom of the flutes (ribs) to the top of the structural steel tubes. The metal deck appeared in good condition with corrosion apparent only at one localized area at the top flange of the deck at exploratory opening No. 5. The webs of the metal deck are perforated while the top and bottom horizontal surfaces are solid. Fiberglass batt insulation is loose laid within the full 7-1/2 inch depth of the deck ribs. The fiberglass insulation was missing at a few locations at exploratory opening Nos. 3 and 5. The fiberglass batt insulation was dry at all locations examined.

A loose-laid filter fabric material below the precast pavers is positioned directly over the EPDM membrane as a separation layer from the precast concrete pavers. Precast concrete pavers are 11-3/4 in. wide x 16-1/2 in. long x 1-1/2 in. thick. The pavers have overlapping ship lap joints at the long sides and are laid in a running bond pattern. Metal clips interlock and retain the pavers together.

Samples of sprinkler piping were cut out from each of the five exploratory openings; labeled and wrapped to preserve the as-discovered conditions, and retained for further evaluation. WJE is currently collecting and reviewing information to determine the cause of the sprinkler leakage and the contributing factors leading to the cause.
Design Considerations

The replacement roofing system must meet current building code requirements for thermal insulation, wind uplift, and fire resistance. The architect, Will Bruder, indicated that wind studies of the building envelope were performed during the original design, which is information that we believe would be useful in our analysis of potential storm events and the subsequent re-design of the roofing system. We have been in contact with the original structural engineer Michael Ishler for the library and have requested this information, but it has not yet been produced.

Regardless of the replacement roofing system type, the roof design should be coordinated with the sprinkler piping replacement so that installation of a piping hanger system can support the new sprinkler piping positioned below the acoustical metal deck. Another important roof design consideration is the detailing for the edge conditions and drainage area along the east and west sides of the roof. These conditions need to accommodate the influences of roof deck deflection and thermal expansion, as well as consideration for expansion provisions from the bands of continuous skylights over the east and west concrete walls. We also recommend the inclusion of an air barrier membrane above the plane of the acoustic corrugated deck within the new roof assembly. An air barrier membrane will reduce air flow through the perforations in deck web and batt insulation and serve to protect the interior spaces from moisture, dust, and debris particles from falling during construction.

Figure 9. Aerial Roof Plan Image Showing Exploratory Opening (EO) Locations and General Area of Displaced and Damaged Roofing.
In our opinion, the roofing system replacement options are as follows:

**Option 1 - Exposed Single-ply Membrane.** Exposed, white-colored thermoplastic membrane (PVC, KEE, or TPO) adhered over a gypsum cover board with two layer rigid board insulation beneath the cover board, mechanically fastened to the corrugated metal deck.

**Option 2 - Ballasted Single-ply Membrane.** Ballasted, loose laid single-ply membrane (EPDM or thermoplastic membrane), over cover board and two layer rigid insulation, and ballasted with lightweight interlocking precast concrete pavers (15 pounds per square foot). This system would be similar to the existing roof system, with enhancements for membrane and ballast paver durability.

**Option 3- Protected Membrane Assembly (PMA).** Protected membrane assembly, utilizing either loose laid EPDM or thermoplastic membrane, on gypsum cover board attached directly on the corrugated deck, protected by two layer extruded polystyrene insulation, filter fabric, and lightweight interlocking precast concrete pavers (15 pounds per square foot), for ballast and walking surface.

**RECOMMENDATIONS**

Based on our observations and findings to date, the following preliminary recommendations are presented for consideration by the City of Phoenix:

1. The two preaction sprinkler systems protecting the Fifth Floor are not salvageable and must be replaced by newly-designed systems. Corrosion in the existing piping and the inaccessibility for inspection, maintenance and repair associated with the existing configuration make repairing the existing system an impractical option.

2. In collaboration with the Library’s stakeholders, we recommend that consideration should be given to the installation of wet pipe sprinkler systems throughout the Fifth Floor for the reasons stated above. Stakeholders should be consulted to review the types of sprinkler system appropriate for the library’s Fifth Floor. The City must then select the type of replacement sprinkler system. WJE intends to provide technical and cost information to the City to aid in making this decision.

3. We recommend an exposed single-ply membrane, or a ballasted single-ply membrane, as described above, for the replacement roofing system. Based on the information available at this time, we believe that the exposed membrane option is more likely to meet the technical requirements of the building code for wind uplift, fire resistance, and energy (insulation R-value). The ballasted single-ply system requires further review and analysis to determine if a lightweight ballast system can meet the wind uplift requirements prescribed by Code. The ballasted system single-ply system also costs approximately 25-30 percent more than exposed single-ply membrane due to the cost of the precast pavers in the assembly.
OPINION OF PROBABLE COSTS

Our opinion of probable cost to replace the sprinkler system on the Fifth Floor is estimated to be between $600,000 and $700,000, which includes the approximate cost of scaffolding or other specialized equipment to access the high ceiling. This cost does not include: demolition of the existing systems, painting and patching, or major modifications to the building’s fire detection and notification system. Our opinion of probable cost to replace the roofing system is estimated to be $1,100,000 - $1,700,000, depending on the final roof design.

In addition to the $1,700,000 to $2,400,000 budget described above, we also recommend a minimum 20 percent construction contingency allowance to account for the exclusions and current unknowns. The actual construction budget can be better defined after the roofing and sprinkler system types and the design concepts are developed further.

REMAINING WJE SCOPE OF WORK AND SCHEDULE

1. WJE is currently collecting and reviewing information to determine, within a reasonable degree of engineering certainty, the cause of the sprinkler leakage and the contributing factors leading to the cause. This activity includes:
   - Review of weather-related information at the time of the loss
   - Review of the event data recorder in the building’s fire alarm system control panel
   - Review of inspection, testing, and maintenance records of the fire sprinkler/standpipe/fire pump and fire detection systems in the building
   - Review of the design drawings and shop drawings for the fire protection systems
   - Arranging an independent laboratory analysis of the sample sprinkler system piping obtained on July 25, 2017.

2. WJE proposes to document the slope of the existing preaction sprinkler system piping above the roof when the piping is exposed for demolition during the construction phase of the new roof covering. This information will be used to supplement the investigation into the cause of the pipe corrosion.

3. WJE will collaborate with other members of the team to finalize a design concept for the replacement Fifth Floor sprinkler system, including pipe location, hanging methods, and aesthetic considerations.

4. WJE will develop contract documents for the replacement Fifth Floor fire sprinkler system, including related monitoring of the system by the fire alarm system.

5. We envision that the time to replace the Fifth Floor fire sprinkler system will require 5 to 6 months, which includes about 30 days to complete the design, another 30 days for procurement, and 3 to 4 months for construction. This estimate assumes that we start design promptly. To account for unforeseen contingencies, the City should allow for 30-60 days of delay to this schedule.

6. WJE is finalizing the roofing system replacement plans based upon the options described above for consideration by the City of Phoenix.

7. We envision that the time to replace the roofing system will require 4 to 5 months, which includes about 30 days to complete the design, another 30 days for procurement, and 2 to 3 months for demolition of the old roof and sprinkler system and for construction of the new roof. Again, this estimate assumes that we start design promptly. To account for unforeseen contingencies, the City should allow for 30-60 days of delay to this schedule.
8. We envision that there will be some overlap in the construction schedules for the fire sprinkler system and roofing system, but recommend that the contractors performing this work be consulted regarding the actual schedule to determine whether the possibility exists to shorten the total schedule by overlapping some of the construction activities.

We hope this information satisfies your immediate requirements. We look forward to completing the necessary work to reopen the Burton Barr Library as soon as possible. In the meantime, please do not hesitate to contact us if you have any questions.

Sincerely,

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