Reroofing Over a Wet Concrete Substrate

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Abstract

The presentation will describe the challenges encountered in a university library reroofing project with a saturated structural concrete deck. The project to be discussed consisted of a complete tear-off of a sprayed polyurethane roof, underlying coal tar pitch built-up roof, and lightweight insulating concrete (LWIC)—all the while keeping the building dry and free of leaks. Moisture probes were inserted to measure the concrete moisture content before and after reroofing. Problems to be solved during construction were mitigation of moisture migration from the old to new roof, addressing LWIC residue and surface roughness, as well as attachment of the base sheet/vapor retarder.

Speaker

Edis T. Oliver, PE — Wiss, Janney, Elstner Associates

Edis Oliver has 40 years’ experience in the roofing industry. He is a former founder and owner of a roofing contracting firm, past president of the Roofing Contractors Association of Texas (RCAT), and recipient of the Curtis Blackwell Memorial Award from the RCAT. He founded and owned his own roof consulting firm, Edis Oliver & Associates, until its acquisition by Wiss, Janney, Elstner Associates in 2006. He has designed and consulted on over 1,200 roofing projects.

Alonso Caro Jr., RRC, RRO, CDT — Wiss, Janney, Elstner Associates

Alonso Caro has nine years’ experience in the roofing industry. He served on the initial roof condition survey and assessment team for this project. He was the key designer of the roof replacement and prepared the CAD drawings and specifications. He was the project coordinator and inspector for the Evans Library, and in that role he performed the moisture testing on the concrete deck, conducted field observations, and prepared the daily reports and progress meeting minutes.
Reroofing Over a Wet Concrete Substrate

This paper describes the problems encountered and overcome during a roof replacement on a major university library housing rare books and collectible artifacts. The existing roofing system consisted of a multilayered roof covering over a light-weight insulating concrete (LWIC) substrate containing significant entrapped moisture. Challenges included determining through testing whether the LWIC was salvageable, as well as collaboration with the contractor to develop the means and methods to be employed to protect the building interior during replacement operations. The roof design requirements included improving the slope and drainage, compliance with energy code requirements, and replacing contiguous masonry wall flashings as well as fall and lightning protection.

Texas A&M University is the largest Tier One research institution in the Southwest, with the main campus at College Station, Texas; 11 branch campuses; and seven state agencies administered by the university. The Sterling C. Evans Library at College Station is the main campus library and consists of four separate buildings. The original library, Cushing Memorial Library, was built in 1927. The first Evans Library Building was built in 1970, and the second Evans Library Building was built in 1979 (Figure 1). The last building, the Evans Library Annex, was built in 2003.

This paper addresses the replacement of the roof on the 1970 building. The presence of moisture in the LWIC, testing of the structural concrete deck, and installation of the new roof system are discussed thoroughly and only apply to the 1970 building. Roof replacement of the 1979 building was also included as part of this project.

BACKGROUND

Wiss, Janney Elstner Associates, Inc. (WJE) was selected in 2011 by Texas A&M University to locate and assess chronic leaks in the 1970 and 1979 buildings. The roof assembly on the 1970 building consisted of an 8-in. structural concrete deck, LWIC sloped to the internal roof drains, and a coal tar built-up roof, followed by polyurethane foam and an elastomeric coating. No expanded poly-styrene insulation (EPS) was present within the LWIC system. The elastomeric coating was deteriorated, thereby exposing the polyurethane foam to direct ultraviolet sunlight. The overall roof area is approximately 47,577 sq. ft. The roof abuts the Cushing Memorial Library 1927 building on the west and the 1979 building on the east. The mechanical penthouse comprises approximately 6,100 sq. ft. of the roof area, and the roof assembly is similar in construction to the main lower roof assembly on the 1970 building (Figure 2).

The 1979 building is a six-story building connected on the east side of the 1970 building. The overall roof area is approximately 42,983 sq. ft. The roof assembly consisted of a reinforced gypsum plank deck over steel bar joists followed by a nailed base sheet; one layer of ¼-in. perlite insulation; one layer of ⅜-in. fiberglass insulation; a four-ply, built-up roof with gravel removed; and 2 in. of polyurethane foam with an elastomeric coating. The elastomeric coating was deteriorated, thereby exposing the polyurethane foam to direct ultraviolet sunlight, similar in scope to the 1970 building.

WJE took nine core samples on the 1970 building, of which five indicated substantial moisture within the lightweight insulating concrete (Figure 3). A number of the leaks appeared near or
beneath the penthouse walls and near the 1979 building wall. To further investigate the moisture entry sources at the 1970 penthouse and 1979 building walls, WJE conducted water testing of the masonry walls using ASTM C1715-10, Standard Test Method for Evaluation of Water Leakage Performance of Masonry Wall Drainage Systems (Figure 4). This test method is a procedure for determining the ability of masonry wall drainage systems to collect water that enters the masonry wall cavity during rainstorms and to direct this water back to the exterior surface of the wall.\(^1\)

No leaks through the penthouse wall or through-wall flashings were found to be present on the 1970 building.

The library building personnel reported that chronic leak conditions have existed between the 1970 building and the 1979 building since the construction of the addition in 1979. WJE made exploratory openings in the 1979 building masonry wall where it abuts the 1970 roof to visually inspect the construction and condition of the through-wall flashing. In addition, exploratory openings were made in the roof assembly of the 1970 building to assess the condition of the roof assembly and presence of moisture in the roof assembly. WJE’s investigation and masonry wall drainage testing revealed a failure of the construction of the through-wall flashing and expansion joint between the 1970 building and the 1979 building. The through-wall flashing depended on an asphaltic-impregnated fabric as the primary waterproofing element. The fabric had split, thereby allowing water to penetrate behind the through-wall flashing, to migrate into the cavity, and ultimately, into the building interior. In addition, the polyurethane foam was installed over the original through-wall flashing, causing any water that was collected in the masonry wall cavity and directed to the exterior to be drained directly into the roof assembly.

As a result of these water infiltration conditions, WJE was asked to develop an immediate repair scope. The through-wall leak condition was corrected by removing the brick and installing a new expansion joint through-wall flashing between the two buildings. Three courses of bricks were removed, and a new copper expansion joint and laminated rubberized asphalt through-wall flashing, with two-piece receiver and removable counterflashing, were installed (Figure 5). Matching bricks were subsequently replaced to complete the work.

The through-wall flashing reconstruction resolved the leak problem in the masonry wall between the 1970 and 1979 buildings. Following the completion of the penthouse cavity wall drainage test and visual inspection of a portion of the through-wall flash-
ing, it was determined that the penthouse through-wall flashings were not contributing water leakage to the interior; however, other leaks in the area of the open field of the roof were still present. Since the roof deck on the 1970 building is structural concrete, the severe leaks manifested themselves at openings in the concrete, mainly at roof drains. However, efflorescence and build-up of salt crystals deposits, ranging from 1 to 12 inches in length, had developed on the underside of the concrete deck, indicating that the concrete deck had cycled through moisture for a long period of time (Figure 6). WJE made additional openings in the roof system at select roof drains and found the surrounding LWIC to be saturated. Since the rooftop covering was polyurethane foam, using infrared thermography to determine the extent of moisture in the roof assembly or insulation was not feasible. As a part of the repair scope, WJE specified reflashing all roof drains.

An additional possible source of moisture entry was created by the presence of roof deck vents presumably installed during original construction with the intent of providing a method for the LWIC to vent and dry. The caps of these vents were sometimes loose and unsecured or missing (Figure 7).

Following the investigatory work and assessment, it was recommended that the roofs on both buildings be replaced.

1970 BUILDING ROOF REPLACEMENT

Following the completion of the repairs, the owner accepted the WJE recommendations regarding the long-term solution to the leak conditions by funding the overall roof replacement for both buildings. Replacing the roof on the 1970 building led to numerous questions with complex answers. The known facts were these:

- Excessive moisture was present in the LWIC concrete.
- Moisture from the LWIC was absorbed into the structural concrete deck.
- An operational library is directly below the structural concrete deck.

The construction of the existing roof assembly is shown in Figure 8.

A significant assessment question was the determination of whether the LWIC was repairable or whether removal was necessary. Investigating the feasibility of removing the moisture was very important, but equally important was the holding power of the LWIC to meet the wind uplift requirements. Nine exploratory openings were made in the 1970 roof, and the results are shown in Table 1. The locations of the core cuts are provided in Appendix A. The openings consisted of a 12-in. x 12-in. square where the roof assembly was removed in layers. The removal of the roof sample in layers permitted determination of the location of the moisture within the roof assembly. It was not known if the moisture was present between the polyurethane foam and the three-ply roof or between the original three-ply and the LWIC. In addition, removing the roof in layers allowed for faster pullout testing on the LWIC. Pullout tests provide evidence of the holding power of the deck to meet wind uplift requirements. Initial pullout testing was performed using the WJE pull test scale and a conventional LWIC base ply fastener. The testing was performed during the assessment of the roof assembly, since the complete removal of the LWIC was only one of the alternatives under consideration. The actual pullout resistance required to meet the wind uplift requirements can vary, based on building

![Figure 7 – View of deck vent. Opening through the roof extends through the LWIC to the structural deck.](image)

![Figure 8 – Cross section of roof on 1970 building.](image)

<table>
<thead>
<tr>
<th>Test Cut</th>
<th>Pull Test</th>
<th>Wet/Dry</th>
<th>Comments</th>
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<tr>
<td>1</td>
<td>50 lb.</td>
<td>Wet</td>
<td>2-in. foam, gravel, 3 plies, 2¼ in. LWIC, and concrete Deck</td>
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<tr>
<td>2</td>
<td>75 lb.</td>
<td>Wet</td>
<td>Similar to #1; only change was 2½ in. LWIC; 10 feet from #1</td>
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<tr>
<td>3</td>
<td>45 lb.</td>
<td>Wet</td>
<td>Similar to #1; only change was 2¼ in. LWIC</td>
</tr>
<tr>
<td>4</td>
<td>60 lb.</td>
<td>Wet</td>
<td>Similar to #1; only change was 3¼ in. LWIC</td>
</tr>
<tr>
<td>5</td>
<td>50 lb.</td>
<td>Wet</td>
<td>Similar to #1; only change was 3½ in. LWIC</td>
</tr>
<tr>
<td>6</td>
<td>20 lb.</td>
<td>Dry</td>
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</tr>
<tr>
<td>7</td>
<td>30 lb.</td>
<td>Dry</td>
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</tr>
<tr>
<td>8</td>
<td>70 lb.</td>
<td>Dry</td>
<td>Similar to #1; only change was 3 in. LWIC</td>
</tr>
<tr>
<td>9</td>
<td>65 lb.</td>
<td>Dry</td>
<td>Similar to #1; only change was 3½ in. LWIC</td>
</tr>
</tbody>
</table>

Table 1 – Summary of roof cut core findings in the 1970 building.
and geographical considerations, but the general threshold sought is approximately 40 lb. As shown in Table 1, seven of the nine tests were above 40 lb., indicating that the LWIC deck was suitable for mechanically attaching a base sheet or vapor retarder.

The presence of a structural concrete deck as the substrate for the lightweight insulating concrete severely limits the LWIC from venting or drying from below. Based on the core sample data, WJE estimated that approximately 60% of the roof area (excluding the penthouse) consisted of saturated LWIC. Because of the extensive amount of entrapped moisture in the LWIC, the unknown amount of additional wet lightweight concrete beyond that observed during the core cuts, and the use of the building, WJE determined that a prudent scope of work required complete removal of the LWIC down to the structural concrete deck. The roofing system to be installed was a fully adhered, torch-down, modified-bitumen vapor retarder; tapered polyisocyanurate roof insulation with an average R-value of 22; three plies of type-IV glass fiber ply sheet; and a smooth, modified-bitumen cap sheet, followed by an asphalt flood coat and gravel. The design called for the tapered insulation to provide the slope to the primary roof drains. The wind design speed for College Station, Texas, required by ASCE 7-10 is 110 mph. ASCE 7 is incorporated into the International Building Code by reference. The 1970 building did not have overflow roof drains, but the design developed allowed for using the roof edge as the overflow since no parapet wall was present and the edge detail was a gravel-guard fascia.

During the initial design and construction, the key question was how to remove the LWIC, dry the deck in a timely manner, and adhere the torch-down vapor retarder in real time while minimizing the risk of leaving the deck exposed to the weather. Another concern was how to keep the water known to be in the LWIC from migrating from the old roof into the new roof during construction. In addition, the extent of moisture in the structural concrete and the ability to dry the concrete would determine adhesion of the torch-down vapor retarder.

Prior to commencing the roof tear-off, the through-wall flashing at the penthouse was replaced using the same methodology as the
expansion joint separating the 1970 building from the 1979 building. Three courses of bricks were removed, and a new copper through-wall flashing and laminated rubberized asphalt, with two-piece receiver and removable counter flashing, were installed. The bricks were subsequently replaced (Figure 9).

To determine the degree of moisture in the structural concrete decks, relative humidity (RH) humidity probes were inserted into the 1970 building concrete deck prior to the roof tear-off.

A sheet metal dam was installed around the probe to prevent known moisture in the LWIC from migrating into the probe zone (Figure 10). As expected, water migrated into the opening and rose to a depth of over 1 in. (Figure 11). The dam protected the probe from submersion.

Following the installation of the humidity probes on the topside of the concrete deck, WJE was given permission and access to install additional humidity probes to the underside of the concrete deck in order to continue to measure the humidity levels of the concrete deck after the completion and installation of the new roof. The methodology for measuring the moisture in the roof concrete deck was in general conformance with ASTM F2170-11, Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in-Situ Probes. This test provides measureable information to determine the moisture content of the existing structural concrete roof deck.

Six moisture probes were installed from the underside (interior) of the concrete roof deck at approximately 3¼ in. deep (Figure 12). The approximate locations of the probes inserted on the topside of the concrete deck are shown in Appendix B.

Twenty-one days after installation of the underside probes, readings of the RH and concrete temperatures were taken. Table 2 provides a summary of the values that

<table>
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<tr>
<th>Date</th>
<th>Avg. Ambient Conditions in College Station</th>
<th>Probe P-1 (near center of north side)</th>
<th>Probe P-2 (near NE side)</th>
<th>Probe P-3 (near SE side)</th>
<th>Probe P-4 (near center of south side)</th>
<th>Probe P-5 (near SW side)</th>
<th>Probe P-6 (near NW side)</th>
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<tr>
<td></td>
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<td>RH % Temp ºF</td>
<td>RH % Temp ºF</td>
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<td>RH % Temp ºF</td>
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<td>99.9 60.4</td>
<td>69.6 60.9</td>
<td>94.2 64.4</td>
<td>75.2 61.1</td>
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<td></td>
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<tr>
<td>1/22/14</td>
<td>48 48 Wet Wet</td>
<td>96.9 61.3</td>
<td>99.9 73.0</td>
<td>99.9 67.6</td>
<td>62.0 59.5</td>
<td>Wet Wet</td>
<td></td>
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Table 2 – Data readings at each probe location on top (exterior) side.

<table>
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<th>Date</th>
<th>Probe Length (in.)</th>
<th>Average Ambient Conditions in College Station</th>
<th>Probe IP-7 (near center of north side)</th>
<th>Probe IP-8 (near NE side)</th>
<th>Probe IP-9 (near SE side)</th>
<th>Probe IP-10 (near center of south side)</th>
<th>Probe IP-11 (near SW side)</th>
<th>Probe IP-12 (near NW side)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RH % Temp ºF</td>
<td>RH % Temp ºF</td>
<td>RH % Temp ºF</td>
<td>RH % Temp ºF</td>
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</tr>
<tr>
<td>3/17/14</td>
<td>3¼ 52 51</td>
<td>91.9 65.1</td>
<td>89.0 64.4</td>
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<td>96.4 77.3</td>
<td>98.6 73.0</td>
<td>98.2 76.3</td>
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<td>84.6 76.9</td>
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<tr>
<td>7/22/14</td>
<td>6 72 85</td>
<td>100 77.5</td>
<td>100 73.5</td>
<td>99.5 76.7</td>
<td>98.4 76.2</td>
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<td>6 65 88</td>
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<td>100 74.5</td>
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<td>100 76.2</td>
<td>68.3 74.8</td>
<td>98.9 77.6</td>
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</tbody>
</table>

Table 3 – Data readings at each probe location on underside (interior).
were gathered on the topside (exterior) of the structural concrete deck, and Table 3 provides a summary of the values collected on the underside (interior) of the structural concrete deck. For the referenced measurements, RH, and concrete temperatures were recorded using a digital handheld concrete moisture meter (Figure 13). The term “wet” indicates that standing water was observed on the concrete surface over the moisture probe, therefore not allowing for readings to be taken. WJE has listed both the top (exterior) and underside (interior) measurements in the tables.

After the replacement of the roof on the 1970 building was completed in May of 2014, WJE installed six additional moisture probes from the underside of the concrete deck at approximately 6 in. deep. The additional probes at a deeper depth in the concrete deck were selected to monitor the moisture content near the top surface of the concrete deck.

The original probes installed on the topside of the structural concrete deck were no longer accessible after the installation of the new roof system. The concern was the long-term effect of the moisture content to the roof assembly and the ability for the concrete deck to dry after the completion of the new roof and the elimination of the moisture source.

During the installation of the additional six probes, data loggers were installed in order to gather RH, temperature, and dew point readings at one-hour intervals on the original 3½-in. depth probe, 6-in. depth probe, and one data logger collecting the ambient temperature, humidity, and dew point of the interior conditions directly below the structural concrete deck. These are being written to an 8-GB secure digital (SD) card that will act as permanent storage of the data collected (Figure 14). In order to retrieve the data, a simple radio frequency (RF) module allows an individual to walk near the probe location and remotely connect to each unit and download the data. Interior conditions have been measured to be maintained at approximately 75-78°F and 50-60% RH.

Portland cement concrete is batched with water, typically ranging anywhere from approximately 6-9% by mass of the concrete. Approximately half or more of this water is consumed during the normal hydration process for cement. The remaining water stays within the concrete and is free to potentially move out of the concrete via diffusion of differential vapor pressure. The rate of moisture movement depends upon RH and temperature of the surrounding environments. For example, for a slab that is exposed to 100% RH and 50°F on one face, free moisture vapor will tend to move from this face to another face with 30% humidity and 70°F.

The RH within concrete declines somewhat due to normal hydration of water;
however, a pressure differential is typically required to significantly dry the remaining free moisture from the concrete. Concrete with an RH of less than 75% provides very little moisture to the outside environment and is thus considered “dry.” The actual threshold for characterizing concrete as “wet” depends on the dew point of the environment around the concrete; but typically, concrete with an RH of 85% or more may provide moisture/vapor to surrounding environments. Concrete with greater than 95% RH would normally be considered wet; and under most building environmental conditions, free moisture on the concrete surface may be expected.

The means and methods to achieve the desired result of adhesion of the torched-down vapor retarder is the responsibility of the contractor. Nevertheless, the methodology employed by the contractor had the potential to affect the final quality of the roof assembly. The adhesion of the vapor retarder was crucial to the wind resistance of the roof assembly because all other components of the roof system are bonded directly or indirectly to the vapor retarder. If the vapor retarder adhesion fails in high winds, the entire roof has the potential to blow off.

The LWIC on the 6,100-sq.-ft. penthouse was determined to be dry and suitable for a roofing substrate, so only the polyurethane foam and built-up roof were required to be removed. The penthouse roof was removed and replaced first in order to avoid debris from the penthouse being transported across the newly finished main roof.

The contractor’s plan was to tear off approximately 2,000 sq. ft. per day on the main roof and dispose of all debris daily (Figures 15 and 16). The tear-off included the polyurethane foam, the built-up roof, and the LWIC. The contractor then intended to sweep the concrete roof deck to remove remaining concrete dust and residue, dry the deck with hot air blowers where necessary, prime the deck, and torch down the vapor retarder each day. The slope to the drains was in the structural concrete deck. The concern regarding moisture migration from the old roof into the new roof assembly was resolved by delaying the installation of the complete roof assembly with new insulation until over half the roof was torn off and protected with the vapor barrier.

The contractor believed the structural concrete deck covered with the torched-down, modified-bitumen vapor retarder would provide a safe and waterproof temporary roof.
during construction. Therefore, approximately half the main roof area was removed and the vapor retarder installed prior to installing the complete insulated assembly, consisting of the tapered insulation; three mopped-down, glass-fiber plies; and the modified-bitumen cap sheet (Figure 17).

While the contractor’s means and methods worked satisfactorily for removing the roof and applying the vapor retarder, an additional unanticipated problem was encountered. The concrete deck finish was not a troweled finish, but instead was a rough finish; and visual observation indicated that adhesion of the torch-down vapor retarder was approximately 40-60%, whereas 80-90% is considered to be satisfactory to meet the wind uplift requirements. Because of the difficulty in cleaning the concrete during the core cut testing, this condition was not discovered during that phase. The contractor was unable to
clean deep pockets or rough irregularities of the concrete surface.

Utilizing the International Concrete Repair Institute (ICRI) Technical Guideline No. 310.2-1997, Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays, the Concrete Surface Profile (CSP) was observed to vary between CSP 7 and CSP 9. Adhesion tests were conducted on the torched-down vapor retarder, and adhesion was determined to be unsatisfactory to achieve the required wind uplift resistance for the project. The adhesion tests generally consisted of cutting random 5- x 5-in. sections and peeling the sheet manually to determine the percent adhered (Figure 18).

As a result of the inadequate adhesion of the torch-down vapor retarder, the decision was made to mechanically attach the vapor retarder using predrilled holes with ¼-in. concrete spike roofing fasteners that penetrated approximately 1½ in. into the concrete deck (Figure 19). The vapor retarder fasteners were installed at the required spacing and frequency provided by the manufacturer, based on the design uplift pressures determined by WJE and field pull testing of the concrete spike roofing fasteners on the structural concrete deck.

The tapered roof insulation system was installed in multiple layers with the polyisocyanurate being laid in 48-in. by 48-in. by 2-in. boards with joints double-staggered (Figure 20). The cover board used was composed primarily of expanded perlite with reinforcing cellulosic fibers and binders.

Additional features installed with the roofing system include a safety tie-off system with permanently mounted attachments supported by anchors inside the penthouse (Figures 21 and 22). Lightning protection cable connectors are flashed directly to the roof deck at the point of penetration into the structure (Figure 23).

![Figure 20 – View of application of tapered roof insulation.](image_url)

![Figure 21 – Permanent wall anchor for fall protection loop mounted on the inside of the penthouse.](image_url)

![Figure 22 – View of permanent wall anchor for lifeline tie-off.](image_url)
Upon completion of all roof system application and plies, the asphalt flood coat and gravel were applied (Figure 24).

CONCLUSION

The overarching problem to be solved in the roof replacement project was how to deal with the known extensive moisture in the LWIC and structural concrete deck and to determine the source of the original moisture. The four most likely sources of moisture infiltration were 1) the through-wall flashing at the 1970/1979 building juncture, 2) the penthouse through-wall flashing, 3) roof drains, and 4) the LWIC vents.

The roof replacement project addressed through-wall flashing conditions, LWIC roof vents, and roof penetrations as possible future sources of water entry into the roof assembly. All roof drains were reflashed and integrated into the roof system. WJE believes the main sources of moisture entry that saturated the LWIC were the LWIC vents and leaks around drain flashings. All conditions were addressed in the roof design and replacement.

The construction means and methods utilized to remove existing moisture and allow for the installation of the new roof while keeping the mission-critical building dry were successful. Only one leak was reported during construction, and that occurred in a corner and was determined to be a window leak. The only unanticipated problem was the inability to obtain satisfactory securement of the torch-down vapor retarder through normal adhesion, thereby requiring mechanical fastening to achieve the required wind resistance. If WJE were to change any procedures for the project, additional tests on the structural concrete to determine the concrete surface profile in advance of commencing tear-off would be performed.

WJE will continue to monitor the moisture levels in the concrete slab to determine the length of time it takes for the moisture content to stabilize and be deemed as a dry deck. WJE believes that due to the deck exposure from below and controlled by interior conditions of approximately 75°F and 55% RH, the moisture content will drop and the structural concrete deck will dry from...
the underside rather than the top of the concrete deck, similar to the drying effects on a concrete floor slab.

The roofing system installed meets the six fundamentals of good roofing:
1. Sound substrate with a concrete deck
2. Good slope and drainage by means of slope in the deck and tapered roof insulation
3. Positive mechanical anchorage
4. Proper flashing of all penetrations
5. Expansion joints at walls
6. Separation of dissimilar materials

The roofing system installed is a multi-ply, fault-tolerant, and redundant system with a hail-resistant gravel surface that is likely to provide outstanding service to Texas A&M University well beyond its 20-year rated life.

REFERENCES