Fallingwater Part 2: Materials-Conservation Efforts at Frank Lloyd Wright's Masterpiece

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Fallingwater Part 2: Materials-Conservation Efforts at Frank Lloyd Wright's Masterpiece

PAMELA JEROME, NORMAN WEISS, and HAZEL EPHRON

Following a 13-year study of building behavior and conservation techniques, Fallingwater's challenging five-year-long restoration is nearing completion.

Dramatically sited over a waterfall in a stream known as Bear Run, Fallingwater, Frank Lloyd Wright's masterpiece, is an icon of twentieth-century design (Fig. 1). Voted in 1991 by the American Institute of Architects as the "best all-time work of architecture," Fallingwater currently functions as a house museum, welcoming more than 140,000 visitors per year. Located in Mill Run, Pennsylvania, 60 miles southeast of Pittsburgh, Fallingwater was originally the weekend home of the Pittsburgh department-store magnate, Edgar Kaufmann Sr. and his wife, Liliane. The house and more than 1,600 acres of surrounding land were donated by their son, Edgar Kauffman jr. [sic], to the Western Pennsylvania Conservancy in 1963.

Fig. 1. Fallingwater, an icon of twentieth-century design, was built in 1936-39. Photograph by Robert P. Ruschak. Courtesy of Western Pennsylvania Conservancy.

A materials-oriented restoration program, involving four phases and lasting from 2001 to 2005, was the direct result of a 13-year investigation of deterioration mechanisms and prototype treatments performed by Wank Adams Slavin Associates LLP (WASA), which led to a graphic conditions assessment, a master plan, and a public peer review.[1] WASA, a New York City–based architecture and engineering firm, first became involved as architectural conservators of Fallingwater in 1988. A detailed examination of the investigative work was published in the *APT Bulletin* in 2001 (volume 32, no. 4).[2] The present paper aims to describe the implementation and results of the project.[3]

Fallingwater consists of a main house and guest house, erected in 1936-39 and connected by means of an enclosed "bridge" over the driveway, which leads to an exterior walkway sheltered by a stepped concrete canopy (Fig. 2). The complex contains approximately 7,000 square feet, over half of which is terraces. The buildings are constructed of stuccoed reinforced concrete, metal lath and stucco over structural-steel framing, local sandstone, and steel casement windows and doors. The stucco, based on white cement, has always been painted.

The main cause of materials-related deterioration was moisture penetration. (Significant structural failures were successfully addressed during the restoration by the engineering firm of Robert Silman Associates, PC. Since December 2002 the main house has been free of the shoring installed in April 1997.)[4] The buildings have always had their chronic leaks, reportedly in

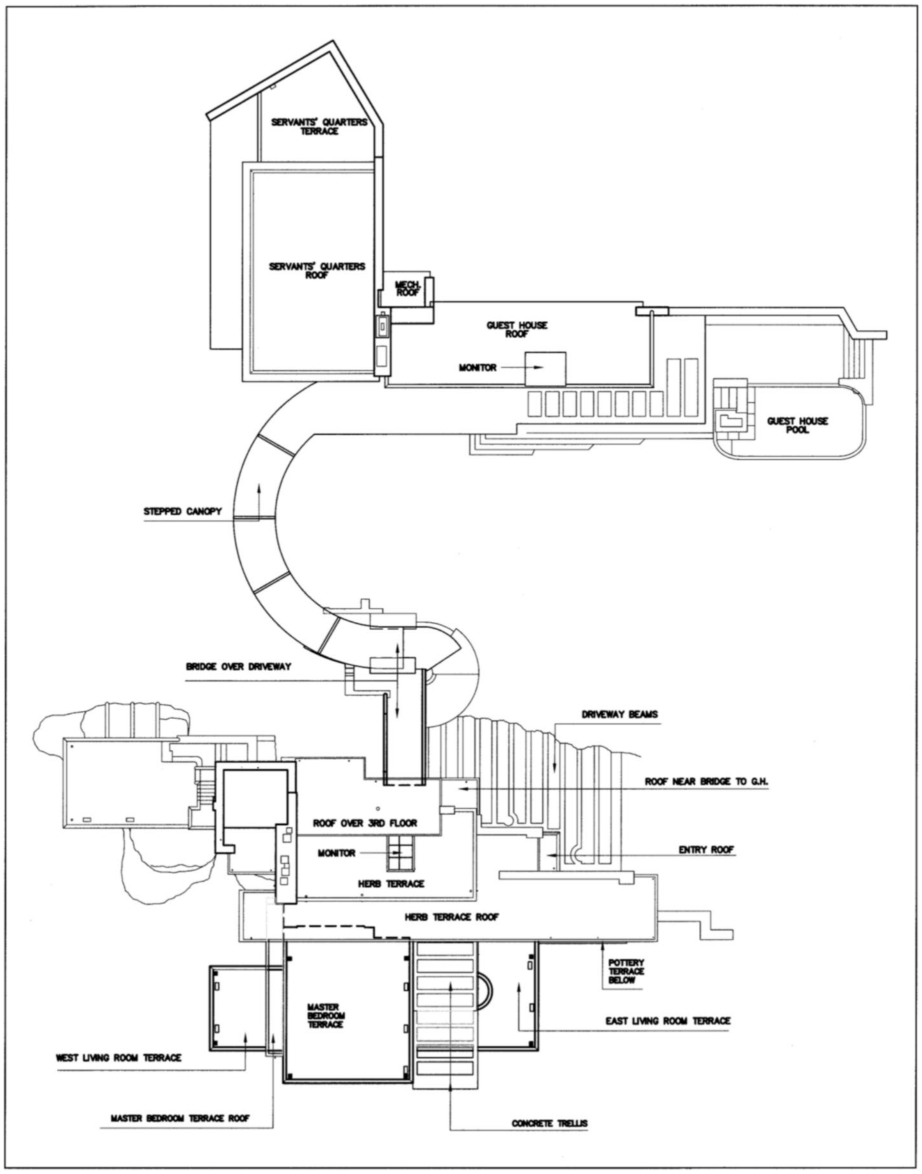

Fig. 2. Key plan of roof levels showing Fallingwater and the guest house. All drawings by WASA. Courtesy of the Western Pennsylvania Conservancy.

more than 50 locations. Some of these problems were from the time the Kaufmanns first occupied the main house in 1937.[5] The distinctive geometry of the buildings, the extraordinary amount of exposed roofs and terraces, and the environmental conditions greatly contributed to these failures. These problems were exacerbated by the lack of through-wall flashings and the unsuccessful design for the termination of roofing and waterproofing membranes.[6] Considerable attention was given to these issues in the previous article in this journal.

Roofs, Terraces, and Skylights

The roofs of Fallingwater were originally built-up, three-ply felt laid in hot asphalt and covered with pea gravel. Roof edges are rounded (roof rolls), an extremely difficult detail for termination of a roofing membrane. Lead gravel stops secured in horizontal reglets were shown on original drawings.[7] However, it is unclear whether or not these features were ever installed. (The only evidence for a perimeter reglet was found on the roof above Edgar Kaufmann jr.'s sleeping alcove, but almost all of the roof rolls have been recast over time, potentially eliminating additional evidence.)

Terraces were waterproofed using an IRMA system (inverted-roofing-membrane assembly) and covered with a walking surface of irregular flagstones, which were extracted from the overburden of the on-site quarry. From a probe of the living-room floor in 1999, it appears that terrace waterproofing ran continuously under the flagstones of interior spaces adjacent to terraces. In addition, where roofs or terraces abut stone walls or concrete parapets, there is no through-wall flashing or original reglet for cap flashing. To further complicate matters, there is no difference in levels between terraces and interior rooms.

To combat these deficiencies, regletted copper cap flashing was installed on the terrace of the servants' quarters relatively early on, and in 1986 regletted lead cap flashing was introduced to most of the remaining terraces. However, lead proved too malleable to withstand the foot traffic of visitors, who tend to lean against the parapet walls to have a better view of the surroundings, resulting in the flashing being knocked out of place. Some roofs had the additional problem of condensation under the membrane. This condition occurred as a result of the lack of a thermal break between the exposed slab edges (roof rolls) and the uninsulated interior ceilings (the undersides of the slabs).

The single-ply 60-mil EPDM-rubberized membrane system, which was installed at most roofs and terraces in 1987-88, began showing signs of failure within a year. The waterproofing system designed by WASA provided a built-in redundancy by using three plies of membranes. The lead cap flashing was removed and replaced with new cap flashing seated in a reglet: 16-ounce copper at terraces (as used earlier on the terrace of the servants' quarters), lead-coated copper at roofs abutting concrete parapets, and lead where roofs (accessible only to the maintenance staff) abutted stone walls.

Roofing by three different manufacturers was used, and all three companies provided waterproofing warranties, a first in Fallingwater's history. J. L. Robinson Roofing, Inc., of Pittsburgh, Pennsylvania, certified in the three systems, performed the work.

A three-ply modified-bitumen waterproofing system manufactured by Siplast

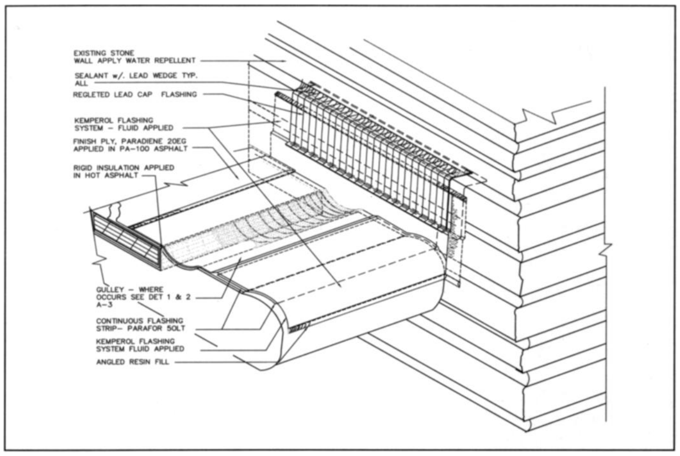

Fig. 3. Axonometric detail of modified-bitumen-roofing system, showing the base flashing terminating on the roof roll and new lead cap flashing inserted into a reglet.

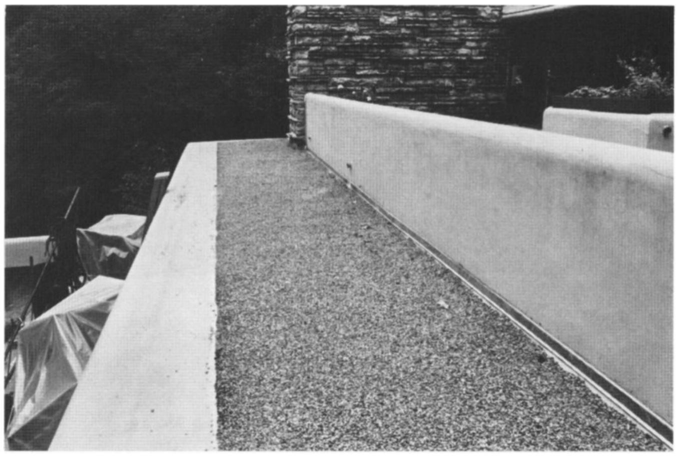

Fig. 4. At the roof-roll edge, the finished base flashing was coated with an elastomeric paint, making it virtually invisible. All photographs by WASA, unless otherwise noted. Courtesy of Western Pennsylvania Conservancy.

was installed on the roofs.[8] A venting base sheet was first torch applied over the primed concrete slab.[9] Fiberglass rigid insulation was adhered with asphalt over the base ply.[10] An intermediate ply was then laid in asphalt on top of this. The finish ply, which was torched down, has a granular surface that was flood-coated with hot asphalt to permit embedment of pea gravel, per Wright's original design intent.

Siplast's typical base-flashing system — foil-faced in either copper or stainless steel — was considered aesthetically inappropriate for Fallingwater. Instead, in collaboration with Kemper System, a polyester fleece–reinforced, liquid-membrane base flashing (Kemperol V210) was used, thus solving the difficult issue of how to terminate the roofing on the roof rolls (Fig. 3).[11] The liquid-membrane base flashing was applied to the midpoint of the roof roll and painted with an acrylic elastomeric paint (PPG Pitt-Flex) to match the stuccoed surfaces, creating a virtually invisible termination (Fig. 4). (In the previous system, the EPDM membranes had been secured with termination bars fastened with impact-expansion anchors, which failed.) Where base flashing abutted irregular stone walls, a mix of one part Type II gray portland cement to two and one-half parts sand was used to parge the substrate smooth.

Waterproofing of the terraces required very accurate stone-by-stone scale drawings of the flagstones to ensure that the stones were returned to their original positions. Stone-by-stone drawings were also generated for the living-room and the covered-bridge floors, since they were both going to be lifted (Fig. 5).[12] The bridge floor required waterproofing because a natural stream that trickles over the boulder at the north elevation is evacuated through a drain in the slab. In the case of the living room, however, nearly the entire room was dismantled (including built-in furniture) to permit access to the top side of the cantilever beams so that cracks could be grouted prior to post-tension-

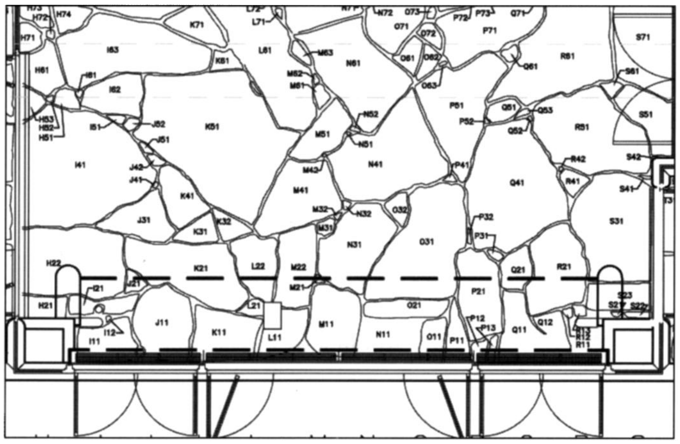

Fig. 5. Stone-by-stone drawings were traced by hand from photo mosaics. The tracings were digitized and then inserted to scale with a grid into the construction drawings. These provided a guide for reinstallation of each flagstone floor or terrace scheduled to be lifted. This detail from a drawing depicts the south end of the living room.

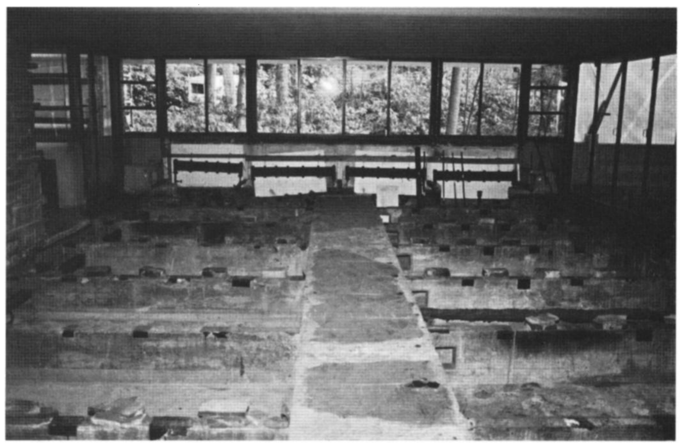

Fig. 6. The preeminent room of the house, the living room, was dismantled and the floor removed in order to grout the cracks in the cantilever beams prior to post-tensioning. One of the four main cantilever beams is visible at the center of the photograph, with concrete joists abutting it to either side.

Fig. 7. Because the finished surface of the terraces consists of flagstones, the waterproofing is an IRMA (inverted-roofing-membrane assembly) system. Drainage mat was laid over the three-ply waterproofing on the master-bedroom terrace.

ing, thus eliminating the potential for substantial lifting of the living room slab during the structural intervention (Fig. 6). (The slab had deflected as much as seven inches as a result of the failure of the main cantilever beams.)

The cantilevered terraces are supported on beams that rise above the slab, allowing for continuous, stuccoed soffits. Between the beams a series of concrete joists creates a system of coffers. The coffers were originally covered with tongue-and-groove redwood decking. This surface had rotted out due to condensation in some areas, and copper hooded vents were remedially installed on affected terraces, probably in the 1960s, to alleviate the condensation.[13] The new system used marine-grade plywood as the substrate for a three-ply, rubberized-asphalt membrane manufactured by W. R. Grace.[14] Bronze angles were introduced below the surface at thresholds to provide a vertical element for application of the base flashing. These angles were counterflashed with sheet copper, which is well concealed between the joint at the edge of the flagstones and the thresholds.

To permit proper subsurface drainage and to provide ventilation above the membrane, thus preventing frost damage, a drainage mat (¼-inch-thick Amerdrain 350, manufactured by American Wick Drain) was laid over the finish ply (Fig. 7). (At some locations, protection board was substituted because of clearance issues.[15]) In addition, for the first time, bilevel sumped drains (1610 drains with perforated stainless-steel extension collars, manufactured by J. R. Smith) were installed rather than the original system of copper tubes (Fig. 8).[16] This substitution required minor cutting of surrounding flagstones so that flat bronze drain strainers could be installed. The extension collars were wrapped in filter fabric (Mirafi FW700) to prevent clogging.

In the past, lifting of the flagstones had caused some breakage because the stones had been laid in a cementitious mortar bed. WASA specified that the flagstones be laid in loose, rounded sand on filter fabric, after a preliminary attempt with pea gravel failed. However, the sand proved unsuitable as well, because the shallowness of the sand layer did not permit adequate bedding, and the flagstones rocked when stepped on. Instead, a dry-pack sand bed, consisting of one part Type II gray portland cement to ten parts sand, was used.[17] The flagstone joints were grouted with one part Type II gray portland cement to three parts sand to match the original aesthetic of the terraces. Closed-cell backer rod (Sonofoam manufactured by Sonneborn) and an elastomeric sealant (Duratex manufactured by Chem Link) were used at the terrace perimeters.[18]

Two skylights, also known as roof monitors, had always leaked. One skylight is on the herb terrace of the main house, over the guest bathroom, and the other is on the guest-house roof, also over a bathroom. The former has planters in the recess at the top of the monitor. These monitors, as well as a planter just above the main-house entry, were reroofed using Kemperol V210. On the herb terrace, new stainless-steel planters, painted to match the Cherokee red of the windows and doors, were installed. At the guest-house roof monitor, an original copper drip edge, found buried under the EPDM membrane, was reinstated.

To the east of the living room, a glazed trellis forms the ceiling over the library area. This skylight was a source of leaks despite its reglazing in 1994.[19] All but one of the four downspouts at the east edge had been blocked, causing ponding on the surface of the trellis. WASA's design for the trellis-skylight restoration introduced a bronze angle clamp with a neoprene gasket (Fig. 9).[20] The concrete surfaces were waterproofed using Kemperol V210. Lead-coated-copper cap flashing inserted into a reglet at the concrete parapet of the master-bedroom terrace counterflashed the installation. Three of the four downspout holes were reopened; the fourth was not because it is located directly over the door that leads from the library to the east living-room terrace.

Small, square skylights that also hold light fixtures in the ceiling of the covered bridge suffered from reoccurring leaks. When the flagstone roof was rewaterproofed, bronze angle clamps with neoprene gaskets were installed at these locations as well.

Concrete and Stucco

From 1989 to 1993 WASA experimented with various patching techniques. Currently, Fallingwater's maintenance staff successfully performs minor concrete repairs using ThoRoc HBA, a polymer-modified cementitious patching compound, by Degussa Building Systems,

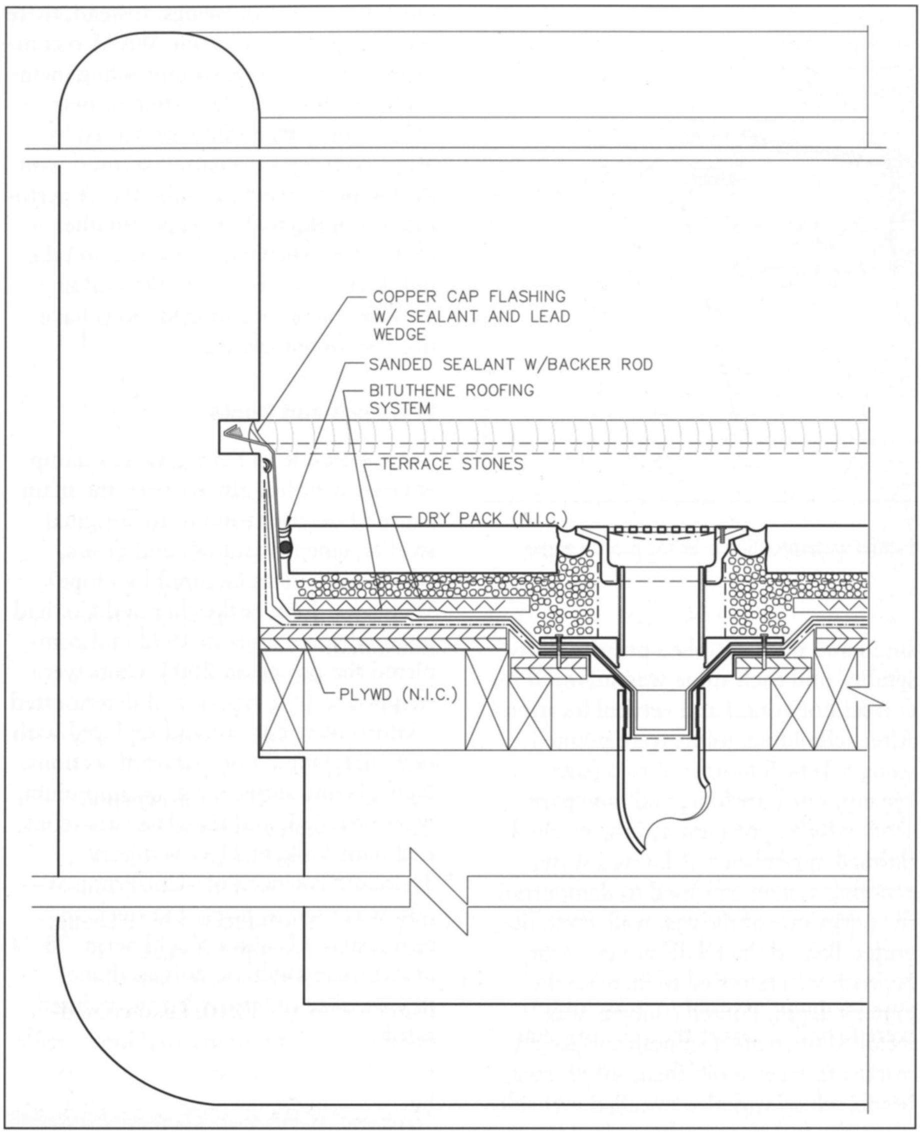

Fig. 8. Detail of a bilevel sumped drain installed on the terraces. These drains replaced the original copper tubes, which could not be integrated properly with the waterproofing and did not permit subsurface drainage.

formerly known as Renderoc HB. However, the concrete stairs to the stream were particularly troublesome. Supported on painted, flat-steel straps that are partially embedded in the treads, the stairs are largely hung from the soffit of the living-room slab. The stairs are occasionally submerged by the stream, resulting in corrosion of the steel straps. In 1991, under WASA's direction, spalls in the concrete steps were removed, and the steel was blast-cleaned, primed, and painted. Both trowel-applied and poured-in-place repairs were attempted, but both failed due to the continuing corrosion of the embedded steel.

These stairs had been rebuilt in the late 1950s after debris carried by the stream during a storm severely damaged them.[21] Because the existing stairs were not original, WASA, in collaboration with Robert Silman Associates, chose to reconstruct them using stainless-steel straps. Worcester Eisenbrandt, Inc., of Baltimore, Maryland, performed this work. The new straps were embedded in the living-room slab. In the process of probing to reveal the existing assembly, an interesting detail was uncovered: the straps were connected to turnbuckles concealed in the concrete. Formwork for recasting was slightly undersized to permit the finished surface to receive the typical ¼ inch of stucco. Existing lighting fixtures recessed into the bottom step were refurbished and reinstalled. The existing supports for the bottom step were different from the rest; they consisted of back-to-back angles anchored into the bedrock of the stream. They were replaced with stainless-steel T-shaped straps of essentially the same appearance (Fig. 10).

Specifying a paint system for the stainless-steel straps proved challenging. The paint had to perform well in damp conditions, as well as when submerged. The stainless-steel components were prepared in accordance with the Society for Protective Coatings standard SSPC-SP-5/NACE No. 1 for White Metal Blast Cleaning, then shop primed using 66 Hi-Build Epoxoline (Tnemec). The submerged stainless steel was field primed with an additional coat of 66 Hi-Build Epoxoline and finish coated with 290 CRU in Wright's signature Cherokee red.[22] For nonimmersion service, the field prime was 1975 Endura-Shield II and the finish coat, 1070 Fluronar.[23]

Stone

The ashlar stonework, of a highly calcareous sandstone quarried from the site, is in good condition.[24] The stone is laid up in uneven courses, with irregular ledges projecting beyond the mortar joints. The original pointing is mostly intact. However, rain and snow accumulate on the projecting ledges, allowing water to percolate through slight separations and hairline cracks in the mortar. The ledges also make it difficult to cut out and repoint the joints. The fact that the stone walls extend uninterrupted from the exterior into the interior without a dampproof barrier is also problematic, although beginning in 1988 remedial through-wall lead flashing has been installed beneath the coping stones at the tops of walls.

Most of the north and east walls, which border the terrace of the servants' quarters and retain the hillside, were repointed by the maintenance staff.[25] In addition, the staff has done some spot repointing of defective joints throughout the complex, using a Type S mortar conforming to ASTM C270-06.[26] However, because of the difficulty of cutting the

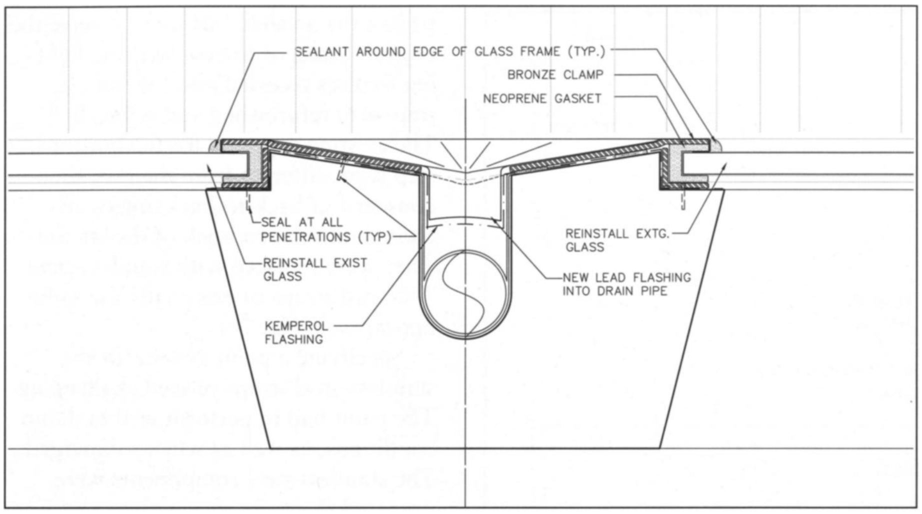

Fig. 9. Detail of the skylight, showing fleece-reinforced liquid waterproofing over the bronze angle clamps.

joints, as well as issues of authenticity, it was decided that repointing of joints with hairline cracks would not be executed. Instead, WASA specified a water repellent to prevent water intrusion. Several water repellents were tested in ProSoCo's laboratories, and Weather Seal Natural Stone Treatment was selected, as it proved the most effective.[27] At the site discrete areas of stonework were treated to test for changes in color and sheen. These test areas were reviewed and approved by the Pennsylvania State Historical and Museum Commission, the state agency having jurisdiction, prior to full-scale application.

Cheek walls made of the same stone border the stairs that lead from the covered bridge to the guest house beneath the stepped canopy. These walls were in fair-to-poor condition. Moisture penetration had caused frost damage to the mortar and heaving of the stones. The east cheek wall was particularly susceptible to these problems because of an inadequate gutter at grade level that was meant to divert run-off water from the uphill area between the guest house and the driveway. Two drainage pipes originating from the guest-house complex, which emerge from the ground in this area, contribute to the moisture penetration of the east cheek wall.[28]

Stone-by-stone drawings were prepared for the east cheek wall, which was dismantled by Worcester Eisenbrandt, Inc. The wall was meticulously measured and photographed prior to disassembly, and each stone was surveyed for correct horizontal and vertical locations. After rebuilding, joints were pointed using a Type S mortar of two parts cement, one part lime, and nine parts sand, which approximated the original finished appearance. A layered waterproofing system was used to dampproof the north side of the east wall along the gutter. Behind the relaid stones, some bedrock was removed to increase the gutter's depth. Poured concrete was installed to create a smooth surface and primed to receive Bituthene 4000 membrane, which was also installed vertically along the foundation of the cheek wall. Hydroduct 220 drainage mat was applied vertically to the foundation on the north side, and terminated into a perforated pipe laid on top of a gravel bed.

The north wall of the guest house is partially bermed into the hillside. The smell of mold is often quite noticeable in the guest house. An electric fan inserted in the chimney and a surface trench drain installed by the maintenance staff have not entirely mitigated this problem. Wood furnishings touching the north wall have sustained minor damage as a result. In April 2000 a test pit was excavated at the exterior of this wall, to verify details indicated on original plumbing drawings.[29] The excavation revealed that a bituminous dampproofing is present but in poor condition. No footing drain was found, although it is indicated on the drawings. Instead, there is a French (gravel) drain. WASA recommended that a new dampproofing membrane be installed, consisting of two plies of Bituthene 4000, protected by Styrofoam rigid insulation secured with PL Premium urethane adhesive. A perforated footing drain wrapped in filter fabric was specified, which would take uphill run-off away from the building. To date, these recommendations have not been implemented.[30]

Windows and Doors

Corrosion due to Fallingwater's damp environment has always been the main cause of deterioration to the original steel casement windows and doors, which were manufactured by Hope's Windows. John Seekircher and Co. had restored some units in 1992 and completed the project in 2003. Units were stripped to bare metal, and deteriorated sections were cut out and replaced with new matching Z- or T-shaped sections. New glazing stops, made of aluminum, were installed, and the glass was reputtied with Vulkem 116 (Mameco/Tremco). Tnemec Poly-Ura-Prime 50-330 was used to prime the steel, and two coats of Endura-Shield Series 73 (a two-part aliphatic polyurethane) in Cherokee red provided the painted finish.

Fig. 10. The stairs to the stream were a 1950s reconstruction, which continued to deteriorate due to the corrosion of the embedded steel straps. During the recent restoration, the stairs to the stream were rebuilt again, this time using stainless steel.

The lack of a drip detail on the stuccoed soffits has also caused problems, particularly because the rounded edges of the roof rolls tend to lead water directly to the window and door heads. In fact, original metal drips located at the head of some of the window and door units are inadequate. WASA has specified the installation of a bead of clear silicone sealant along the perimeter of the stuccoed soffits to act as a drip edge (999-A Silicone Building and Glazing Sealant manufactured by Dow Corning). Installation of the silicone drips will occur after repainting. In some instances, depending on visibility, a groove may be cut into the soffit surface instead.

At locations where Wright's design called for inserting glazing into the stonework without a frame, deteriorated caulking will be removed, surfaces primed, and new backer rod and sealant installed (1200 Primer and 795 Silicone Building Sealant manufactured by Dow Corning).[31]

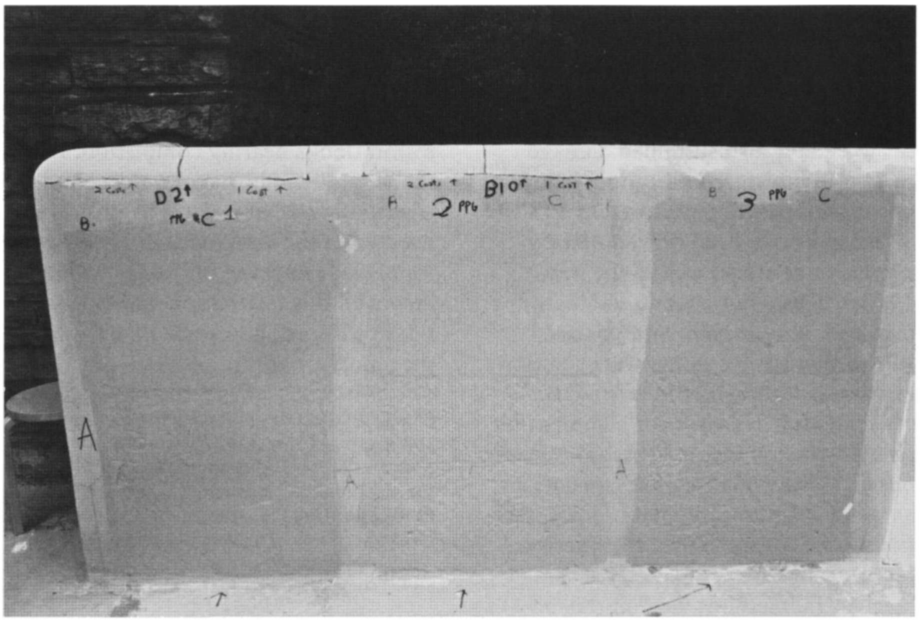

Fig. 11. Paint testing involved the review of approximately 120 variations, some of which are seen here, applied by four different manufacturers on vertical, horizontal, and rounded parapet top surfaces.

Paints and Coatings

In the spring of 2001 WASA began a detailed, comparative product evaluation in an attempt to resolve the failure of ProSoCo BMC 90, a silicone emulsion paint that WASA had specified subsequent to some paint testing done in 1990. Fallingwater has an unusual amount of skyward-facing stuccoed surfaces, which never had the benefit of a waterproofing membrane. The ProSoCo paint performed very well on vertical surfaces but biological contamination affected the horizontal surfaces within months of application.[32] (Organic debris from the surrounding vegetation is particularly plentiful at Fallingwater.)

Prior to full-scale repainting with BMC 90 in 1994, an acrylic system by Thoro was in use. This paint had to be renewed on more-or-less an annual basis, gradually reducing vapor permeability.[33]

Four manufacturers were invited to participate in the 2001 paint-testing program: ProSoCo, PPG, Keim, and Silin. The horizontal surface projecting to the south of the guest-house roof parapet was selected as the test area. Three paint-stripping methods were tested for removal of the BMC 90, keeping in mind that Bear Run is an environmentally protected stream. Because a silane water repellent (ProSoCo's Sure Klean Weather Seal SL 40) was used as primer under the BMC 90 in 1994, there was some concern that a new water-borne paint system could experience adhesion failure.[34]

Each manufacturer was assigned a testing area that included horizontal, vertical, and rounded parapet-top surfaces that were subdivided into bands where the three paint-stripping methods had been tested (Fig. 11). Altogether, approximately 120 paint variations were applied in the early summer of 2002 and allowed to weather over the winter. Sample preparation and paint systems varied widely according to manufacturer and in some cases included the application of a biocide. (ProSoCo's preparation of the substrate included treatments of D/2 Architectural Antimicrobial by Cathedral Stone Products, Inc., or their own BioWash, and some of PPG's preparation applied the disinfectant Mildew Check Multi-Purpose Wash.)

WASA reviewed the samples in October 2002 and again in March 2003. ProSoCo's BMC II exhibited failures similar to those of BMC 90. PPG's epoxy-based paints were considered too glossy for Fallingwater's aesthetic. The Keim paint systems (modified potassium silicate) recommended the resurfacing of the stucco finish, a labor-intensive procedure that was deemed unacceptable and exhibited failures in the samples. Only Silin's Silith (silicone-modified potassium silicate) provided performance and application characteristics that were suitable. This system was also compatible with paint stripping using only the power-washing method.[35] WASA recommended that preparation also include application and thorough rinsing of D/2 Architectural Antimicrobial to remove biological soiling prior to painting. A large-scale application of Silith was performed to the stepped canopy in July 2003, but it exhibited erosion and irregular discoloration by October 2005.[36]

In November 2005 PPG began testing eight different exterior-paint systems on the guest-house canopy. On both horizontal and vertical surfaces, half of the prepared surfaces were treated with D/2 Architectural Antimicrobial and the remaining half with Mildew Check Multi-Purpose Wash. Two types of alkali- and moisture-resistant primers were applied. A series of acrylic-based latex topcoats of various compositions were then applied. They are being monitored on the horizontal and vertical surfaces, as well as the parapet roll tops.[37]

Interiors

The interiors of Fallingwater are finished with a white cement plaster similar to the exterior stucco. The interior surfaces have also sustained damage related to moisture infiltration. The last full-scale repainting occurred in 1987-88 using Thorosheen (a water-based acrylic paint introduced in the mid-1970s). This paint is dark and highly textured. Recent paint analysis has shown that earlier paints were smoother and sometimes lighter in color.[38] Because of multiple layers of incompatible paints (which under microscopic examination show evidence of delamination), as well as curatorial issues of interpretation of the correct finish, the interiors require paint stripping. After several mechanical methods were tested, a small needle scaler suggested by the maintenance staff was successfully used in February 2002 to strip the director's office in the servants' quarters in a test program.

PPG Perm Sealer Vapor Barrier, a low-moisture-transmission primer, is now being used as a vapor barrier for the ceilings under affected slabs to prevent moisture from migrating from the interior to the top of the slab.[39] Speedhide Interior/Exterior Acrylic Latex Alkali-Resistant Primer 2-203 is then applied to both walls and ceilings to block stains. Two coats of Pure Performance Paint follow as the finish paint.[40]

Anecdotal evidence implied that the interior and the exterior were always painted identical colors.[41] However, extensive sampling and analysis has revealed that an early repainting campaign used a much lighter, peach-colored oil-based paint on the interior. It is speculated that this change may have been made because the interior surfaces naturally appear darker than the exteriors; thus, using a lighter-color paint would have given the illusion that the two colors were the same. Fallingwater's curatorial staff has chosen to paint both interior and exterior the same color. Full-scale interior repainting, requiring substantial plaster patching, takes place periodically during the winter months on a room-by-room basis.[42]

Conclusion

After 13 years of building investigation and the evaluation of prototype repairs, Fallingwater's five-year, $11.5-million restoration is nearing completion. For the first time in its history, the complex is virtually free of leaks. The project has resulted in the safeguarding of an American icon. However, only time will tell how well this restoration addresses the site's problems, and some issues, such as the paint, are still to be resolved.

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HAZEL EPHRON is a registered architect. She joined WASA in 1974, where she is now a senior partner. She is partner-in-charge of WASA's preservation department and has overseen the department's work for 15 years. She is recognized as a waterproofing expert in the New York metropolitan area.

Notes

1. Wank Adams Slavin Associates (hereafter, WASA), "Volume I: Existing Conditions Survey" (unpublished report, September 30, 1999). WASA, "Volume II: Evaluation and Recommendations" (unpublished report, September 30, 1999). The five-hour peer review was by invitation only and occurred on April 10, 1999, at the Carnegie Museums of Pittsburgh. The meeting coincided with the opening of the exhibit Merchant Prince and Master Builder: Edgar J. Kaufmann and Frank Lloyd Wright. After presentations by WASA and Robert Silman Associates, the invited technical experts reviewed the proposed materials restoration and structural-engineering intervention. The peer reviewers included Randall J. Biallas, Nicholas L. Gianopoulos, Neil Levine, John Garrett Thorpe, Bruno Thurlimann, Martin E. Weaver, and Eric Lloyd Wright. In addition, the floor was opened for questions from Western Pennsylvania Conservancy's board members and technical advisory committee, Frank Lloyd Wright experts, and the press, in that order. Refer to Western Pennsylvania Conservancy, "Protecting Fallingwater for the Future: A Private Forum" (unpublished transcript, April 10, 1999).

2. Norman Weiss, Pamela Jerome, and Stephen Gottlieb, "Fallingwater Part 1: Materials-Conservation Efforts at Frank Lloyd Wright's Masterpiece," *APT Bulletin* 32, no. 4 (2001): 44-55.

3. WASA's restoration team consisted of Hazel Ephron, partner-in-charge; Pamela Jerome, project manager; Norman Weiss, then conservation scientist; Keith Gianakopoulos, project architect; and Rene Fan, Felix Fernandez, and Jorma Locci, draftspersons. Fallingwater's staff has also been enormously helpful in this process, including Lynda Waggoner, director; Cara Armstrong, curator; Michele Risdal-Barnes, former curator; Jeff Gaul, director of maintenance; Dan Johnson and Albert Ohler, maintenance staff; Cecil Kifer, former maintenance staff; and Blaney Sproul, former site superintendent.

4. For structural problems, refer to Robert Silman, "The Plan to Save Fallingwater," *Scientific American* (September 2000): 88-95.

5. Weiss, Jerome, and Gottlieb, 45.

6. It cannot be overemphasized how problematic Wright's deliberate choice not to install through-wall flashing for aesthetic reasons has been to the waterproofing of these buildings. In general Wright's use of different construction materials that penetrate each other has complicated an inherent design-based pathology.

7. Frank Lloyd Wright, "Detail of Existing Roofing," undated drawing, referred to as drawing 3602.117 by the Frank Lloyd Wright Foundation.

8. The Siplast roofing system used was primer, PA-1125 Asphalt Primer; base ply, Paradiene 20TS; intermediate ply, Paradiene 20EG; finish ply, Paradiene 50LT. These membranes are a high-quality, modified SBS asphalt, reinforced with fiberglass mat.

9. The underside of this type of membrane has alternating stripes of asphalt that become tacky when heated in a torch-down application. The stripes of asphalt bond to the concrete slab, while the adjacent unbonded stripes provide venting channels to move water vapor. Additionally, the ceilings below affected slabs were painted with a vapor barrier as a primer to further alleviate condensation.

10. WASA's specifications initially called for fiberboard insulation, but the contractor convinced us to change this as none of the materials removed from the existing roofs were dry.

11. Kemperol V210 is a cold, fluid-applied resin, which, when combined with Kemperol fleece, cures to form a seamless, reinforced, monolithic polyester membrane system. WASA, "Detail 1/A-4: Iso. – Flashing Detail at Roof Edge" (Fallingwater Phase 2 (1B) construction drawings, May 21, 2002).

12. WASA, "Enlarged Plan, Drawing A-2" (Fallingwater Phase 3 construction drawings, May 21, 2002).

13. Weiss, Jerome, and Gottlieb, 50.

14. The W. R. Grace waterproofing system consisted of a base ply of Procor Fluid-Applied Waterproofing Membrane (a two-part self-curing rubber), followed by two plies of Bituthene 4000 (a peel-and-stick rubberized-asphalt membrane). The membranes were turned up at the edges and sealed with Bituthene Mastic (a rubberized-asphalt–based mastic).

15. According to the curator, the lack of clearance at the herb terrace was further exacerbated by the fineness of the filter fabric around drains, and the drains at this location were not sumped. These conditions allowed water to get under the mat, causing the entire overburden to float. In addition, the drainage mat's needle-punched fabric permitted flexing, creating a trampoline effect. This phenomenon, combined with the shallowness of the sand bed, caused the flagstones to rock, cracking the grout joints.

16. WASA, "Detail 5/A-2: Terrace: Flashing/Drain Details" (Fallingwater Phase 2 (1B) construction drawings, May 21, 2002). Copper tubes were the original method of drainage for both terraces and roofs. These tubes penetrated the slab but did not integrate properly with the waterproofing system. In the case of the terraces, there was also no means to collect subsurface drainage. As a result, water around the perimeter of the tubes tended to freeze, damaging the tubes and the concrete structure of the terraces. The southeast corner of the master-bedroom terrace was recast in 1991, during WASA's investigative and prototype-repair period.

17. The first good rain after application dampens the cement and slightly solidifies the sand so that the setting bed does not shift, but there is not enough cement to "glue" the flagstones down. The amount of cement does not significantly alter the permeability of the sand bed.

18. WASA, "Project Manual for Fallingwater Restoration Phase 1: Guest House/Servants' Quarters and Herb Terrace" (unpublished technical specifications, August 22, 2001); "Project Manual for Fallingwater Restoration Phase 2 (1B): Main House: EK, Sr.'s Terrace, Roof over EK, jr.'s Study, Roof over 3rd Floor, Entry Roof and Roof near Bridge to Guest House" and "Project Manual for Fallingwater Restoration Phase 3: Living Room, Master Bedroom Terraces and Roofs, Enclosed Bridge, Cheekwalls and Foundation Waterproofing" (unpublished technical specifications, May 21, 2002).

19. This reglazing was not designed by WASA.

20. WASA, "Detail 4/A-9: Detail" (Fallingwater Phase 3 construction drawings, May 21, 2002).

21. WASA, "Fallingwater Volume 3: Concrete Repairs/Coating Tests" (unpublished report, 1991), 2.

22. Paint analysis of the windows indicated that the original finish color was a Venetian red (Munsell 8.3 R 3/5). This shade was changed to Wright's Cherokee red by Kaufmann jr. in 1976. The Venetian red was identified by Frank Welsh with Ilene Tyler of Quinn Evans|Architects. Quinn Evans|Architects with Frank S. Welsh, "Fallingwater: Historic Finishes and Colors" (unpublished report, February 28, 1990).

23. WASA, "Project Manual for Fallingwater Restoration Phase 4: Stairs to Stream Reconstruction" (unpublished technical specifications, May 21, 2002).

24. X-ray diffraction performed in ProSoCo's laboratories identified the sandstone as containing 51.5% calcite, 47.1% quartz, and 1.3% microcline. ProSoCo, "Laboratory Report: Fallingwater Water Repellency Evaluation" (unpublished report, May 15, 2000), 2.

25. Scuppers that drain the terrace were traced and found to dump water into the fill behind the terrace walls. During the process of rewaterproofing the terrace, the scuppers were rebuilt and pipes attached to reroute the water.

26. The mix consists of two parts Type IA gray portland cement, one part hydrated lime, and eight parts ASTM C144 sand, closely matching the original.

27. ProSoCo, "Laboratory Report: Fallingwater Water Repellency Evaluation" (unpublished report, May 15, 2000). The other products tested included Weather Seal Siloxane WB, Weather Seal H40, and Sure Klean Custom Masonry Sealer.

28. The Western Pennsylvania Conservancy is in the process of implementing the master landscaping plan designed by Marshall Tyler Rausch of Pittsburgh, Pa.; the drainage pipes will be rerouted as part of the work.

29. Frank Lloyd Wright, "Sheet Numbers 4 and 6," unpublished drawings issued January 28, 1939, and March 14, 1939, referred to as drawings VIII-21 and VIII-23, respectively, by Avery Library Archives.

30. WASA, "Project Manual for Fallingwater Restoration Phase 3: Living Room, Master Bedroom Terraces and Roofs, Enclosed Bridge, Cheekwalls and Foundation Waterproofing" (unpublished technical specifications, May 21, 2002).

31. Ibid. Saflex, an ultraviolet protective laminated glazing installed in 1989, is now delaminating. The new sealant will be installed upon replacement of the 1,800 square feet of glazing.

32. Heidi Turner, research and development technical analyst, to ProSoCo, Inc., dated April 11, 2001.

33. WASA, "Volume 1: Fallingwater: Conservation Analysis for Concrete and Stone Masonry" (unpublished report, January 18, 1989), II/6. Concrete surfaces had been sandblasted in 1976, greatly damaging the original stucco. The stucco had been patched with Thorite (a cementitious patching mortar) modified with Acryl 60 (an acrylic admixture).

34. Row A was application of Peel Away 2 (a methylene chloride–based paint stripper, manufactured by Dumond Chemicals, Inc.) followed by pressure washing at 900 psi, then application of Peel Away 1 (an alkaline paint stripper) followed by pressure washing at 900 psi, and lastly application of ProSoCo's Limestone and Masonry Afterwash (acetic acid) agitated on the surface with a brush followed by pressure washing at 900 psi. Row B was pressure washing only at 900 psi; Row C was application of Peel Away 2 followed by pressure washing at 900 psi.

35. WASA, "Exterior and Interior Paint Report" (unpublished report, April 15, 2005).

36. The large-scale application, which was unsuccessful, was undertaken by Fallingwater's maintenance staff using the product undiluted.

37. PPG's relationship with Fallingwater is documented as early as 1951, when the exterior was painted with a PPG oil-based paint. During 1971-72 PPG paints were again considered and tested as a replacement for failing exterior paint.

38. Integrated Conservation Resources, Inc., "Paint Analysis Services: Fallingwater Bear Run, Pennsylvania" (unpublished report, May 2001), 7-10.

39. Most buildings use insulation on the warm (ceiling) side to provide a thermal break, but in this case it would severely compromise Wright's original design.

40. WASA, 2005. Pure Performance Paint has some interesting environmental attributes including low odor, zero VOC content, and antimicrobial properties.

41. Quinn Evans|Architects with Frank S. Welsh, 1990. The exterior finish color is Munsell 8.2 YR 7.2/3.7 and was determined from historic exterior paint that survived on the soffit of the living-room slab. Frank Welsh, with Ilene Tyler of Quinn Evans|Architects, performed this research.

42. Thus far the south end of the living room and the covered bridge were repainted in 2004, the master bedroom in January 2005, and the guest bedroom in January 2006.