ISSUE 2/2015 ▪ VOLUME 32 ▪ NUMBER 2

Hoffmann Architects

Journal

Journal of architectural technology published by Hoffmann Architects, Inc., specialists in the rehabilitation of building exteriors.

What Went Wrong?

Diagnosing Building Envelope Distress

John J. Hoffmann, FAIA and Deborah J. Costantini, AIA

With so many diverse components contributing to building envelope assemblies, it can be challenging to determine which of these myriad elements was the likely cause of a failure. Even seasoned building owners, managers, or facility professionals may find themselves faced, from time to time, with a confounding problem at the building exterior. These needn't be catastrophic to be vexing, although sometimes, what began as a small, persistent issue can turn the corner suddenly to become a major fiasco.

▲ Unless the problem is correctly diagnosed and repaired, it will continue to worsen, sometimes to the point of major failure.

Unfortunately, without proper diagnosis, building envelope problems are unlikely to go away. While superficial repairs might seem to redress the condition, more often than not, they actually make the situation worse, usually by trapping water or introducing materials incompatible with the existing construction. In the examples that follow, we explore some of the varied causes of distress and failure in facades, plazas and building entrances, parking structures, and roofs, and look at the systematic, if sometimes complex, process of uncovering—and resolving—the source of the problem.

Masonry

When our design professionals first visited the building pictured in Figure 1, they found loose brick and mortar below the windows, failed sealant at jambs, aluminum sills bent upward at the front edge (Figure 1a), and, most notably, significant gaps between the head of the window frame and the opening (Figure 1b). Concerned that the windows may have fallen in their openings, the project team conducted a follow-up window investigation to find out what had gone wrong.

If the windows were indeed dropping into the wall, we would expect to see loose, missing, or otherwise failed fasteners when we removed windows for testing. We saw none. Moreover, our meeting with the window manufacturer confirmed that nothing was amiss with the attachment method or installation, both of which followed standard details.

What we found is that rather than the windows falling into the wall, the opposite was true – the wall was moving upward around the windows.

Building materials expand and contract at different rates. Brick, for example, expands over time, whereas concrete shrinks. In this fairly typical cavity wall construction, the brick masonry is only a one-brick-thick veneer. Behind it is an open cavity space to allow for drainage, along with insulation and an air/vapor barrier. On the other side of this cavity is concrete masonry back-up, which provides the structure of the wall; unlike solid brick masonry

John J. Hoffmann, FAIA is President of Hoffmann Architects. A nationally recognized expert on the building envelope, he advocates for design detailing to improve construction outcomes. Deborah J. Costantini, AIA, Senior Architect, has extensive experience in the diagnosis and resolution of building exterior distress.

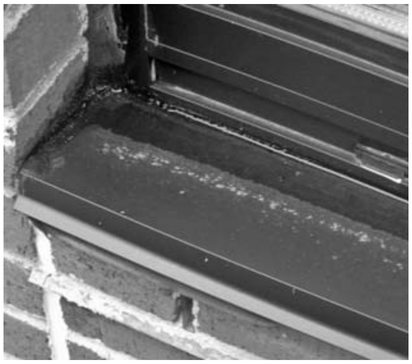


Figure 1a: Masonry expansion led this sill to bend upward at the front edge.

Figure 1b: As the brick veneer expanded, it pulled upward away from the window.

construction used in historic structures, newer buildings use brick only at the wall surface.

When combining multiple building materials in a single assembly, the design and construction must accommodate for their sometimes contradictory properties and behaviors. In response to moisture and humidity, brick expands slowly over time. The most common way to provide for this tendency is to place shelf or relieving angles at regular intervals along the height of the wall, with expansion joints beneath. By separating the brick masonry into regular segments and allowing those segments room to expand, these joints prevent cracking and failures.

Unfortunately, this building was designed without relieving angles or horizontal expansion joints. Although there are other ways to accommodate movement, these are limited to low-rise buildings, and no such provisions were made here. As a result, the cumulative expansion of all of the brick masonry over the entire four-story building led to substantial differential movement, particularly at the top floor, where the brick had expanded so much that the window sills were now sloped inward, toward the window, allowing water to collect along the frame (Figure 1a).

With the window units anchored to the concrete back-up, which shrinks over time as it dries out, and no provision for the expansion of the face brick, the window units remained in place while the brick veneer grew, making it appear on first glance that the windows were sinking. Only through a comprehensive masonry and window investigation could the real problem be uncovered.

In the example presented in Figure 2, relieving angles are present, unlike in our previous example. However, here we found displaced and spalled brick courses immediately above and below the relieving angle. The question was: why?

A test probe into the distressed brick revealed asphaltic sheet flashing that was lapped but not sealed, which allowed water to travel between the overlapping layers. In addition, the flashing had deteriorated and was no longer providing much protection at all. As water migrated through the porous brick and lingered in the deteriorating flashing, it led to corrosion of the steel relieving angle. As steel corrodes, it expands, placing outward pressure on the surrounding brick and leading to cracks and spalls.

Observing the beginnings of damage at the wall surface, a well-meaning soul with a caulk gun went around and sealed up the open joint at the relieving angle. Unfortunately, this joint was open for a reason: the porous mortar above the relieving angle is meant to allow any moisture inside the wall to discharge. Once this escape route was covered over with impervious sealant, water collected inside the cavity wall.

As the outside temperature rose and fell, trapped water underwent successive freeze/thaw cycles, expanding as it froze and contracting as it thawed. These changes in temperature and pressure forced off pieces of the outer surface of the brick, and led to the displacement visible in Figure 2a, in which the face brick is nearly detached from

Figure 2a: Brick displacement due to poor flashing design and freeze/thaw cycling.

Figure 2b: An attempt to fix spalled brick with sealant made matters worse.

the facade. As deterioration worsened, the same good intentions that led the maintenance staff to apply sealant to the mortar joint brought them back again, caulk gun in hand, to fill in more sealant in and around the spalled brick, inadvertently making the problem worse (Figure 2b).

Plaza/Terrace

From the outside, the main entrance ramp and plaza shown in Figure 3a looked great: the plaza surface was clean and even, with no heaved pavers or uneven joints. Visitors to the building would have no idea of the horrors within: the spaces one and two levels below the ramp were so riddled with water damage that they became virtually unusable (Figures 3b and 3c). What was going on?

The corroded steel beam in Figure 3b sits directly under an expansion joint in the plaza, where the main entrance ramp meets a level surface; Figure 3a shows this expansion joint from above, with the ramp extending upward to the left of the joint. Notice that the trench drain, at the right (red arrow), is downhill from the expansion joint (black arrow). Every time it rains, water runs down the ramp toward the bottom, where, traveling along the first available path, it meets the open expansion joint and travels into the occupied space below. With the only drain situated downhill from the expansion joint, much of the water has already found its way into the building before it ever gets there.

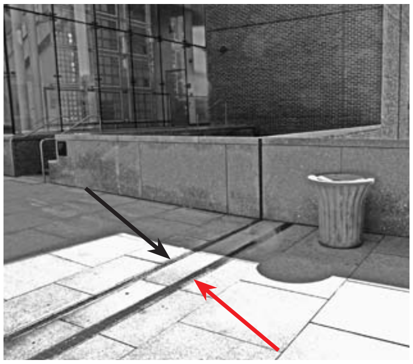
The lesson here is that problems due to faulty waterproofing and drainage design don't always look like problems on the surface. The pristine surface of this plaza belies the extensive deterioration below, where water infiltration has led to corrosion, disintegration of fireproofing materials, efflorescence, staining, and severe water damage to finished spaces. That's why it's so important to properly investigate the source of leaks, and to address the underlying problem.

Garage

Precast, prestressed concrete double-tee construction has become one of the most common types of parking garages, particularly in suburban areas. Although factory fabrication of the precast members affords improved concrete quality control, the weak point for these garages tends to be the hundreds of steel connections that hold together the prefabricated units. Welded in the field, these connections tend to be the first point of failure, and when they fail, they tend to break not one by one, here and there, but catastrophically, in quick succession.

The garage pictured in Figure 4 is a typical four-level freestanding parking structure constructed of precast concrete units in a double-tee (TT) configuration. The distinctive star-shaped pattern of corrosion and spalling in Figure 4b occurred at regular intervals along many of the connections between precast members (Figure 4a). With steel reinforcing present throughout the concrete deck, why was corrosion concentrated at these locations?

An investigation into the garage conditions, including test probes at areas of corrosion and spalling, provided some answers. As moisture penetrated through failed sealant joints at the double-tee connections, it encountered the embedded steel elements that connect one flange to the next. In addition to weld defects that ranged from poor configuration to faulty execution, the garage was constructed with mild carbon steel connections, rather than stainless steel. Despite a coat of anti-rust paint, the connections at this thinnest part of the concrete flange succumbed to corrosion, which extended outward from the welded plate, along the embedded structural steel.



▲ **Figure 3a:** The only drain (red arrow) was downhill from an expansion joint (black arrow).

▲ **Figure 3b:** Plaza leaks corroded steel and melted fireproofing beneath the faulty joint.

▲ **Figure 3c:** The plaza looked great, but leaks left rooms below looking anything but.

Figures 4a (left) and 4b (right): Corrosion concentrated at flange connections in this precast concrete garage due to inappropriate materials, weld defects, and sealant joint failure.

Figures 5a (left) and 5b (right): Insufficient air entrainment of this concrete surface left freezing moisture no room to expand, leading to severe disintegration.

More concerning, the fractured welds, combined with the missing concrete and loss of embedment area at the beam flanges, mean that the connection capacity at many of the intersections between precast units was significantly compromised. Although the distinctive reddish-brown rust stains and chipped concrete are obvious indicators of, at a minimum, a maintenance issue, what they don't immediately reveal is the serious nature of the damage from a structural standpoint.

Previously, a misguided repair attempt applied patching material to the surface (some of the remaining repair compound is visible in Figure 4b). Not only were these patches performed poorly, with insufficient surface preparation, they failed to address the source—and the ramifications—of the failure.

Precast garages often have some cast-in-place elements, and the way in which these different types of concrete interact can impact the longevity of the garage, particularly at parking surfaces. In Figure 5, portions of a tri-level precast garage became quite an eyesore—and presented hazardous conditions for pedestrians—when crumbling concrete led to uneven surfaces. Scaling was so severe in some locations that all that remained of the cast-in-place topping was loose aggregate and sand.

Even where the *washes*—humped concrete areas designed to promote drainage—had been replaced, signs of distress had already recurred, including spalls and cracks. During the condition assessment, we found that the concrete was unusually soft and porous, offering little resistance to chipping.

The freeze/thaw cycling typical of winters in the North can pose problems for even the best designed and constructed parking garages, as these open structures are exposed to temperature fluctuations inside and out. As water absorbed by the concrete freezes and expands, it imparts great internal pressures. Repeated cycles of freezing and thawing can weaken the cement matrix and lead to deterioration. To mitigate this condition, concrete manufacturers incorporate microscopic air pockets through a process known as *air entrainment,* which allows water to expand as it freezes without causing damage to the concrete.

In this case, however, petrographic testing revealed that air entrainment of the cast-in-place concrete at curbs and washes was insufficient. As freezing moisture in the concrete expanded, it had nowhere to go, so it pressed outward, leading to cracks, spalls, and eventually, to near total disintegration of the parking deck surface. Previous repair efforts temporarily improved concrete integrity, but even in these new areas, cracks had been left unaddressed, indicating that these locations, too, would likely deteriorate unless the poorly prepared concrete was completely replaced.

Roof

In October 2012, during Hurricane Sandy, a catastrophic roof failure occurred at a suburban data center (Figure 6). Situated on a ridge overlooking a river, the facility's relatively open terrain left it exposed to the full force of the high storm winds. Although the roof structure and membrane assembly were designed to withstand even the intense wind pressures of a hurricane, the roof succumbed to the storm, the membrane lifting and the insulation becoming displaced below. We were charged with the question: was this failure due to insufficient design, faulty construction, or both? And how might the damage be repaired, with an eye to preventing similar incidents in future storms?

The first step was to perform calculations for the original assembly, to determine whether the design had been adequate to handle the intense wind load. Reviewing the original drawings, our design professionals determined that the structural roof deck was designed not only to meet the building code in effect at the time of construction, but to withstand loads that were even greater than those mandated by code.

The roofing assembly, composed of an ethylene propylene diene terpolymer (EPDM) membrane adhered to polyisocyanurate insulation board, also met accepted standards for wind uplift. Our research found that both the roofing assembly and the proprietary metal fascia at the roof edge exceeded even the most restrictive building code requirements set by the state. Beyond the mandates of the code, additional wind analysis based on wind speeds of up to 145 miles per hour found that even in severe conditions, the roof design should have been sufficient to withstand the wind load without failure.

Having ruled out design error as the cause of the failure, the project team then looked to workmanship and detailing of the roof installation. Field investigation revealed several factors at play; one was that insulation boards could be easily lifted from the roof deck, and were not fully adhered. In some cases, asphalt adhesive coverage below the boards was a scant 25 percent. Many of the boards were "cupped," or warped, which contributed to the poor adhesion. The temperature of the asphalt at the time of installation may also have been a factor.

At the roof edge, the EPDM membrane had been cut off at the top of the parapet, rather than extending over and down the outboard face of the blocking (Figure 6b). In addition, wood blocking in the areas of failure was of insufficient depth to engage the fasteners. Compounding this lack of securement were voids beneath the edge metal where it extended over split-face concrete masonry units. These openings, along with the disengaged fasteners, allowed positive pressures to penetrate the underside of the edge metal.

Other construction defects, including large voids in the concrete roof deck and faulty cricket construction that allowed moist air to accumulate under the membrane, also contributed to the roof blow-off. Although any one of these conditions might in itself have caused the problem, the likely source was some combination of all of them. Despite the sound design of the structural deck and roofing assembly, a host of preventable errors during construction led to complete failure of the roof during the storm.

At a residential building on a college campus, severe ice dams at the roof led to leaks at both above-grade levels and the basement ceiling (Figure 7). During a very cold winter, one might expect to see some ice damming on older structures, but this was new construction, just a few years in service. Clearly, more than just bad weather was to blame for the persistent leaks and hazardous ice formation.

Our investigation uncovered several problems in both design and construction. Unbalanced ridge and soffit venting, combined with thermal penetrations in the attic insulation, allowed warm air to collect at the underside of the eaves, warming the roofing materials sufficiently to melt the snow. Once this snow melt reached the gutter and drip edge, it re-froze (Figure 7a). Over time, this repeated thawing and freezing created an accumulation of ice at the gutter, which allowed water to back up under the roofing shingles and penetrate to the building interior (Figure 7b).

Based on notes made on the original drawings, we surmised that the ice

Figures 6a (left) and 6b (right): Roof blow-off caused by insufficient insulation adhesion, poor edge detailing, and other construction defects.

and water barrier failed to meet code requirements, and was insufficient to the demands of the climate. Given the complexity of the roof, the majority should have been protected with ice and water barrier beneath the roofing shingles; according to the drawings, only a small portion actually was.

In addition, the original drawings differed substantially from as-built conditions, which can contribute to construction deficiencies. By not accurately reflecting the existing roof framing or attic floor, the drawings did not provide sufficient guidance for the installers for ice and water barrier terminations, particularly where roof and wall areas intersect.

The lesson here is that coordinated drawings are critical to avoiding deficiencies in construction. Had the drawings adequately accounted for roof ventilation, attic insulation, ice and water barrier installation, and, critically, the intersections between various roof and wall areas, then the ice damming could have been prevented. As it is, the college will need to disrupt living accommodations at its facility and expend time and money in reconstructing a roof that is only a few years old.

Curtain Wall

Winter weather was also the catalyst for building envelope failure at a very different type of building in a very different type of setting: a glazed curtain wall in the middle of Manhattan (Figure 8). During a blizzard, a portion of the louver and frame system detached and fell from the building (Figure 8a and 8b), landing on a roof setback (Figure 8c), as well as on the roof of an adjacent building and the street below. Fortunately, no one was injured.

After reviewing existing documents and examining fallen and damaged material, our forensic team interviewed the curtain wall manufacturer to complete the picture of the probable cause of failure. Constructed in 1962, the curtain wall system employed a series of bolts and clips to secure the framing to the building structure. Newer curtain wall buildings use locking nuts to counteract vibration, but in buildings of this vintage, nuts and bolts working loose was not uncommon, even when some type of lock-washer was used. During the investigation, we found enlarged holes on some outrigger clip connections, which was consistent with fastener loosening.

Figures 7a (top) and 7b (bottom): Ice dams at eaves led to extensive leaks at the building interior and required replacement of the roof just a few years after it was installed.

Other construction defects that likely contributed to the failure were the absence of an anneal slip, used to prevent galvanic action between dissimilar metals, between steel and aluminum outriggers, as well as failure to weld mullion splice sleeves. The expansion joint in the area of failure was only about ¼ inch wide, yet calculations and manufacturer data predicted an estimated ¾ to 1 inch of expansion over the twenty-foot aluminum mullion.

Although weather conditions at the time of failure were harsh, they were not sufficient to have explained a failure of this magnitude. Instead, a combination of factors, ranging from design errors to construction omissions to limitations in the curtain wall securement system of the time period, coalesced to result in a life-threatening disaster. Something as small as failure to properly account for the material properties of an assembly – in this case, expansion, galvanic action, and seismic forces – can lead to calamity if not considered during design and construction.

Solutions

With so many components working together to create a weather-resistant, thermally insulating building enclosure, it's easy to see how compromising just one of these, whether through design omission or construction error, can have a disastrous effect on the entire system. Where more than one flaw exists, the probability of failure is compounded.

For historic structures, including Modern-era buildings of the mid-twentieth century, time and exposure can aggravate flaws inherent to the original design or fabrication, increasing the risk of building envelope distress. Older buildings, therefore, demand diligent maintenance and prompt, appropriate repairs to keep emerging issues at bay, lest they devolve into major disasters.

(continued on page 8)

representative projects

Building Envelope Rehabilitation

Recognizing early indicators of deterioration and developing proactive repair programs is critical to good stewardship of the building envelope. Hoffmann Architects has worked with clients in commercial, institutional, government, healthcare, and other sectors to resolve problems at the outset, saving the expense of emergency repairs.

Beginning with an investigation into existing conditions, our architects and engineers develop detailed recommendations for repairs that address problems at their source. Hoffmann Architects has provided building envelope services for diverse buildings, including:

UBS North American Headquarters
Stamford, Connecticut
Roof Rehabilitation

The George Washington University Funger Hall
Washington, District of Columbia
Plaza and Facade Rehabilitation

Pfizer World Headquarters
New York, New York
Building Envelope Rehabilitation

Ethical Culture Fieldston School Lower School
New York, New York
Building Envelope Rehabilitation

Phoenix Companies Headquarters
Hartford, Connecticut
Plaza and Garage Rehabilitation

Eversource Energy (formerly Northeast Utilities)
Berlin, Connecticut
Garage Rehabilitation

M&T Bank Headquarters
Buffalo, New York
Plaza, Entrance Pavilion, and Garage Rehabilitation

State University of New York Purchase College
Purchase, New York
Building Envelope Rehabilitation

ARINC International Headquarters
Annapolis, Maryland
Leak and Brick Displacement Remediation

Middlesex Hospital
Middletown, Connecticut
Building Envelope and Garage Rehabilitation

Fairfield Public Schools
Fairfield, Connecticut
Building Envelope Master Plan and Rehabilitations

State of Connecticut Superior Courthouse
Stamford, Connecticut
Plaza Investigation and Rehabilitation

Amgen Inc.
West Greenwich, Rhode Island
Garage Assessment and Repair

Cathedral of Saint Joseph
Hartford, Connecticut
Building Envelope Rehabilitation

Crowne Plaza Hotel Times Square
New York, New York
Facade, Roof, and Garage Rehabilitation

Fordham University Dealy Hall
Bronx, New York
Facade Rehabilitation

Wellesley College Tower Court Residence Halls
Wellesley, Massachusetts
Historic Building Envelope Restoration

Folger Shakespeare Library
Washington, District of Columbia
Exterior Rehabilitation

Choate Rosemary Hall, Archbold Building in Wallingford, Connecticut. *Facade Rehabilitation.*

Bertelsmann Building, 1540 Broadway in New York, New York. *Glass Curtain Wall Investigation and Repair.*

Hoffmann Architects, Inc.
2321 Whitney Avenue
Hamden, CT 06518

ADDRESS SERVICE REQUESTED

Figures 8a (top), 8b (middle), 8c (bottom): A portion of this glazed curtain wall detached and fell dozens of stories.

(continued from page 6)

But buyer beware: newer buildings, as we have seen, often fare no better, subject as they are to the cut corners and shoddy workmanship of fast-track projects that tend to be more about getting it done than getting it done right. Even high-end construction can fall prey to oversights in design or craftsmanship that stem from lack of communication among trades, inexperience with emerging technologies and new building systems, failure to account for intersections between building elements, or a host of other factors.

Although the ideal situation would be to anticipate and prevent building envelope problems before they occur, we are living in an imperfect world, and building exterior distress is often inevitable. The good news? The next best thing to "build it right the first time" is "fix it right the first time." With the correct diagnosis, you're well on your way. ■

JOURNAL offers AIA/CES Learning Units
Earn Health, Safety, and Welfare (HSW) continuing education credit for reading the JOURNAL.
To learn more, visit www.hoffarch.com.

JOURNAL is a publication of Hoffmann Architects, Inc., specialists in the rehabilitation of building exteriors. The firm's work focuses on existing structures, diagnosing and resolving problems within roofs, facades, windows, waterproofing materials, structural systems, plazas/terraces, parking garages, and historic and landmark structures. We also provide consulting services for new building construction, as well as litigation and claim support.

For address changes, free subscriptions, or information on the topics discussed in this issue, contact our Marketing Department at 800-239-6665, news@hoffarch.com, or:

2321 Whitney Avenue
Hamden, CT 06518
203-239-6660

1040 Avenue of the Americas, Ste. 14C
New York, NY 10018
212-789-9915

2611 Jefferson Davis Highway, Ste. 200
Arlington, VA 22202
703-253-9800

www.hoffarch.com

Editor/Production: Alison Hoffmann