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Journal

Preventing and Treating Failure in Glazed Curtain Wall Systems

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In a general sense, the term “curtain wall” refers to an exterior wall that does not support loads other than its own weight. Curtain walls are therefore non-structural, and serve solely to protect the building from the elements. Seismic and wind forces on a curtain wall are transferred to the supporting structure at anchorage points, where the curtain wall frame is attached to the building, generally at floors or columns.

large expanses of glass, which shrouds the building in a seemingly weightless veil of light.

Glazed curtain walls were a marvel when they were first developed, and since that time American cities have seen the construction of a great number of glass buildings. With soaring heights and sweeping views, glazed curtain walls offer desirable office, retail, and residential spaces that are faster and less expensive to construct than are their bearing-wall counterparts. As glazed curtain walls age, however, many of their components reach the end of their service lives. When leaks and drafts become recurrent problems, it can be difficult to determine the best course of action.

Armed with an understanding of basic curtain wall construction and familiarity with common problems, the prudent building owner or facility manager can identify and manage curtain wall distress with appropriate, proactive strategies.

Development of Curtain Wall Technology

The development of the elevator in the late 1800s launched the national impetus toward high-rise buildings. With the advent of structural steel and reinforced concrete, architects

Although curtain wall systems may incorporate a variety of materials, we will focus on the type that is so ubiquitous, it has effectively become synonymous with the words “curtain wall”: the glazed curtain wall system. Glazed curtain walls usually consist of a metal frame, often aluminum, with in-fills of vision and spandrel glass. Other materials may be interpolated between glazing units, including brick veneer, precast concrete, metal panels, and thin stone. The hallmark of these systems is a focus on



▲ Workers repair failed gaskets at a glass curtain wall high-rise.

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The Basics of Curtain Wall Construction

Glass curtain walls consist of two basic components: the glass and the frame. How these two elements are manipulated, including the proportion, properties, and anchorage of each, constitutes the essential distinction among individual curtain wall systems.

The Frame

Composed of steel, aluminum, multi-laminate glass, or other resilient material, the frame is the support grid that holds the glass in place.

Stick systems are curtain walls at their most basic, with individual *mullions*, or framing elements, assembled in the field.

Unitized systems apply the same design principles as stick systems, but sections of the curtain wall are assembled in the shop and installed as a unit.

Unit mullion systems combine the pre-assembled panels of unitized systems with the multi-story vertical mullions of stick systems. Upright mullions are installed first, with horizontal mullions and glazing installed as a unit.

Column cover and spandrel systems articulate the building frame by aligning mullions to structural columns. Pre-assembled or field-assembled infill units of glass or opaque panels are fitted between the column covers.

Point-loaded structural glazing systems eliminate visible metal framework by incorporating tension cables, trusses, glass mullions, or other custom support structures behind the glass panels. Glazing is anchored by brackets or by proprietary hardware embedded in the glass.

The Glass

Curtain wall glazing ranges in price, durability, impact resistance, safety, and stability, depending upon the manufacturing process. The most common types:

Float glass was developed in the 1950s by Alastair Pilkington, whose breakthrough *float process* enabled production of the large glass sheets that characterize curtain wall construction. Molten glass is fed into a bath of tin, where it flows along the surface, forming smooth glass with even thickness.

Annealed glass undergoes a controlled heating and cooling process that improves its fracture resistance. Despite its improved durability, annealed glass can break



into sharp pieces, and many building codes limit its use in construction.

Tempered glass is chemically or thermally treated to provide improved strength and shatter resistance. On impact, tempered glass shatters into tiny pieces that are less likely to cause injury than are larger shards.

Heat-strengthened glass and **chemically strengthened glass** fall between annealed and tempered glass in terms of strength. Unlike tempered glass, strengthened glass can be sharp when shattered, so it is best suited to areas with limited access. Scratches in strengthened glass have also been shown to compromise its strength.

Laminated glass bonds two or more sheets of glass to an interlayer of plastic, generally polyvinyl butyral (PVB), which holds the glass in place if broken. Laminated glass is often specified for curtain walls in hurricane-prone regions or in areas requiring blast protection.

Insulating glazing units (IGUs) improve thermal performance through the use of double or triple panes of glass, separated by a space that is filled with air or with an inert gas.

Spandrel glass, which is darkened or opaque, may be used between the head of one window and the sill of the next. To create the illusion of depth at spandrel areas, transparent glass may be used in a *shadow box*, with a metal sheet at some distance behind the glass.

For all their variation, glass curtain walls retain the same basic components as they did when Willis Polk first envisioned them in the early 1900s. Understanding the composition of glass and frame, as well as the relationship between them, is vital to maximizing the longevity of a glazed curtain wall system. ■

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and engineers no longer needed to rely on the exterior wall system to support the building structure, permitting the practical construction of taller and lighter buildings. One of the first glass curtain walls was constructed in 1909 in Kansas City, Missouri, and designed by architect Louis Curtiss. The Boley Clothing Company Building used glazed curtain walls framed by traditional cast iron and terra cotta ornaments, combining new technology with established period design elements.

Soon thereafter, in 1918, the groundbreaking Hallidie Building was completed in San Francisco. Architect Willis Polk took advantage of the properties of reinforced concrete to create cantilevered floor slabs, which permitted the glass curtain wall to appear to float at the building exterior, unencumbered by columnar supports.

Curtain wall technology thereby established, these early examples were soon followed by the first glass curtain wall high-rise in New York City, Lever House, along with the United Nations Secretariat Building, both completed in 1952. Mass production of sheet metal and glass following World War II enabled larger areas of glass, and technological developments in sealants and glazing compounds permitted more reliable glazing anchorage. By the latter portion of the 20th century, aluminum had widely replaced steel as the primary framing material, owing to industrial innovations that permitted its inexpensive extraction. Aluminum has the additional benefit of being easily extruded, and it is not prone to corrosion as is structural steel.

In recent years, glass curtain wall construction has become commonplace, moving out from city centers to suburban office parks, malls, hospitals, and universities. The abundance of curtain walls means that it is especially important to understand the significance of

common symptoms of aging, wear, and distress, and to respond promptly at the first signs of trouble.

Causes of Distress and Failure

Like all building elements, curtain walls have their weak points. Knowing what to look for, how to extend the service life of a curtain wall system, and when it's time to retain a consultant are critical to avoiding costly and disruptive failures. Although issues vary with frame material, construction method, and glazing type, there are some common concerns that design professionals look for when evaluating the condition of a curtain wall system.

Deflection

Aluminum has many advantages as a curtain wall framing material, but it has the distinct disadvantage of deflecting approximately three times as much as steel does for a given load. Even when the amount of deflection doesn't compromise the strength of the aluminum members, it still may pose a danger in that the glass may be forced out of place. To protect against excess deflection, mullions are extruded into shapes that maximize the *area moment of inertia*, or resistance of a particular cross-sectional shape to bending stress. Wide-flange elements, such as I-beams, have particularly high area moments of inertia, which is why this profile is used so often in construction.

To reduce deflection in a curtain wall assembly without adding excess depth to the frame profile, steel reinforcement may be added to aluminum mullions. This method protects the steel from exposure to the elements, while taking advantage of its load-bearing properties. However, water penetration into a steel-reinforced system can also lead to deflection as the steel corrodes and expands, causing the aluminum to bow outward.

Glazing Failure

Condensation on glass curtain walls may be an indication that the relative humidity of the interior is too high, and an adjustment to heating and cooling equipment is necessary. However, condensation may also point to failure of the curtain wall system. If moisture is observed between panes of glass in an IGU, the hermetic seal may have failed, permitting air intrusion into the interstitial space and compromising thermal performance, as well as visibility.

Hairline cracks in glass may indicate excessive thermal loading, particularly if the glass has a coating, such as a low-e film or tint. When the sun strikes the glass, it heats the exposed portion of the pane, causing it to expand. The unexposed edges remain cool, creating tensile stress that can lead to cracking, particularly in glass that has not been heat-strengthened or tempered.

Nickel sulfide (NiS) inclusions can cause glass to shatter suddenly, sometimes years after installation. All glass has microscopic imperfections, or inclusions, that result from the manufacturing process. Generally speaking, these are of little concern. The exception is NiS inclusions in tempered glass, which have led to a number of dramatic glass failures. As glass is heated during the tempering process, NiS converts to a compressed (alpha) phase. When the glass is cooled rapidly to temper it, the NiS lacks sufficient time to return to a stable low-temperature (beta) phase. Over months or years, the trapped NiS transitions to the beta phase, expanding as it does so. The resultant pressure leads to micro-cracks in the glass, which can propagate until the glass structure is thoroughly compromised, and the glass shatters in what seems to be a spontaneous breakage.



▲ Loose gaskets or seals.



▲ Streaked glazing.



▲ Gaskets disengaged from glazing.

In an existing structure, ultrasound, laser imaging, or heat soak testing may be used to identify NiS inclusions; however, such test methods can be labor-intensive and expensive. For buildings with multiple glass failures, the pros and cons of full glazing replacement should be weighed against the costs of testing and isolated replacements.

Gasket and Seal Degradation

A common cause of curtain wall problems is failure of the gaskets and seals that secure the glazing. *Gaskets* are strips of synthetic rubber or plastic compressed between the glazing and the frame, forming a watertight seal. Gaskets also serve to cushion the glass and to accommodate movement due to wind, thermal, or seismic loads.

As they age, gaskets begin to dry out, shrink, and crack. Subjected to ultraviolet radiation and freeze-thaw cycles, the elastic material degrades, much like an old rubber band. At first, air spaces created by the shrinking,

dried gaskets admit air and moisture into the system, leading to condensation, drafts, and leaks. As the gaskets further disintegrate, they may loosen and pull away from the frame. Without the support of flexible gaskets, the glass loses stability and may shatter or blow out. For this reason, it is important to maintain and routinely replace gaskets to keep the curtain wall system operational and safe.

In lieu of compression gaskets, some curtain wall systems use *structural sealant*, usually a high-strength silicone product, to secure the glass to the frame. Like gaskets, sealants have a finite service life. Signs that it's time to replace perimeter sealants include shrinking or pulling away from the surface, gaps or holes, discoloration, and brittleness.

Design or Construction Defects

As with any type of construction, curtain walls are subject to the shortcomings of human capability. Material failure and age-related deterioration

may be common causes of curtain wall distress, but many catastrophic and costly failures are attributable to avoidable errors.

Missing, incorrectly applied, or otherwise deficient sealants at frame corners and other intersections can lead to serious water infiltration issues. Failure on the part of the contractor to follow manufacturers' guidelines, and on the part of the design professional to provide sufficient oversight, can result in water damage that is both difficult to access and expensive to repair.

Flashing detailing, too, requires fastidious attention to prevent leaks at intersections between the curtain wall and other building elements. Without detailed contract documents that fully describe and illustrate perimeter flashing conditions, along with coordination between the curtain wall installer and construction manager during installation, flashings may not be adequately tied or terminated, permitting water to enter the wall system.



▲ Leaks and drafts.



▲ Displaced mullion covers.



▲ Broken glass.

Poorly installed trim covers and accessories can pose a danger to people and property below, particularly when adhered using structural glazing tape alone, without mechanical attachments. Construction sequencing is of particular importance, as swing staging and scaffolding can damage or displace mullion covers. Maintenance activities may also be responsible for loose trim elements.

Unforeseen structural interactions among building elements may lead to failure if the curtain wall has not been properly engineered. Inadequate provision for differential movement, as well as incorrect deflection calculations, may be responsible for cracked or broken glass, seal failure, or water intrusion. Glass and framing must be evaluated not only independently, but as a system, with consideration given to the impact of proximal building elements.

Finally, **haphazard erection techniques** may be responsible for premature curtain wall failure. Any of the above construction defects may result from unskilled and poorly supervised installation. Sloppy sealant application, for example, can block drainage outlets at the glass perimeter, or *weep holes*, trapping water inside the wall system. Scratches to glass during installation may diminish its strength and durability, and improperly applied window films also may decrease the lifespan of the glass.

Evaluation and Testing

If leaks, deflection, etched glass, or other issues have become a concern, an architect or engineer should conduct a systematic evaluation of the curtain wall system, beginning with close visual inspection. ASTM International provides test standards for the evaluation of air and water penetration, as well as structural performance of glass in curtain wall applications. Tests for water penetration, such as ASTM E1105, use a calibrated spray rack system with a positive air pressure differential to simulate wind-driven rain. ASTM E783 specifies test procedures for determining field air leakage at specific pressures.

Glazing that displays systematic scratches or other defects after installation may need to be evaluated for structural integrity. In such cases, a representative sample of glass units may be removed and tested under laboratory conditions. ASTM E997 is one test method for determining the probability of breakage for a given design load.

Considerations for Rehabilitation

Shrinking of neoprene exterior gaskets is a common concern, and it is not always easy to fix. Although some curtain wall systems, such as those that incorporate pressure bars, may permit gasket replacement without glazing removal, by and large it is difficult or impossible to replace gaskets

without removing the glass. *Wet sealing*, which involves cutting out worn gaskets and adding perimeter sealant, may be an option; however, wet sealing does not generally result in a reliable water barrier, and it creates an ongoing maintenance demand. Where possible, it is best to maintain the original glazing system.

Anodized aluminum frames should be cleaned as part of a routine maintenance program to restore an even finish. For powder coats, fading and wear can be addressed with field-applied fluoropolymer products, although these tend to be less durable than the original factory-applied thermoset coating. Other coatings on the market aim to improve durability, but their track records and maintenance requirements should be considered prior to application.

Should major rehabilitation or replacement of a curtain wall be indicated, a number of factors should influence the design process, including:

Thermal Performance

Even fifty years ago, curtain wall systems weren't as energy-efficient as was solid wall construction. With energy costs and environmental considerations now topping the list of building management concerns, retrofits that increase the efficiency of glazed curtain walls have become an attractive option for improving overall building performance.



A Gaps at frame corners.



A Loose or missing weather stripping.



A Scratches and hairline cracks.



▲ Evaluation may include measurements of gasket hardness (top) and of glazing alignment (bottom).

However, before investing in facade upgrades for the sole purpose of reducing energy expenses, it's a good idea to evaluate the projected time period for cost recovery. While minor retrofits may pay for themselves relatively quickly, some major upgrades may have a protracted payback period, depending upon the existing energy profile.

Incorporating insulating glass is one of the primary methods for enhancing the thermal properties of glazed curtain walls. Some frame systems may be retrofitted to receive IGUs, although the double-pane glass is generally thicker and heavier than its monolithic counterparts, requiring, in most cases, structural modifications.

Low-emissivity (low-e) glass can improve building energy performance by keeping heat indoors during winter, and outdoors during summer. Low-e coatings reflect infrared radiation without diminishing visible light, reducing *Solar Heat Gain (SHG)*, a rise in indoor temperature due to heat from the sun. Some coatings may be added as a retrofit to existing glazing, but use cau-

tion, as incompatible films may lead to differential heating and stress cracks in the glass. Low-e glass is also available as a glazing replacement option.

Aluminum is a highly conductive material, meaning that it readily transfers heat between the exterior and interior of the building. *Thermal breaks*, made from a non-conductive material such as plastic or rubber, prevent heat transfer across the metal. Properly designed thermal breaks of adequate thickness can substantially improve the thermal performance of an aluminum curtain wall frame, as well as provide resistance to condensation.

Because spandrel areas are not generally exposed to the building interior, as vision glass is, they are more subject to condensation and differential movement due to temperature extremes. *Back pans*, which are metal sheets designed to prevent water infiltration in spandrel areas, may require superimposed insulation to mitigate temperature fluctuation.

Recent changes to state and local energy codes, including adoption of the 2012 International Green Construction Code (IgCC) and International Energy Conservation Code (IECC), may place more stringent requirements on curtain wall performance than did the codes in effect when the building was constructed. Depending upon the jurisdiction, even minor rehabilitation projects may need to comply with the tougher codes.

Structural Capacity

In addition to the *dead load* of the curtain wall components themselves, the facade must be able to withstand *live loads* impinging upon it during operation. Particularly for tall buildings or for those in hurricane zones, wind loads are a prime design consideration. Curtain wall anchorage should be able to withstand lateral forces, while remaining flexible enough to

permit movement of the curtain wall and underlying building structure. Seismic loads present a similar design challenge, as glazing pockets must retain sufficient flexibility to accommodate building sway without shattering the glass.

Fire Safety

The open design of a suspended curtain wall makes it susceptible to the spread of fire. For this reason, *firestops* are required at the perimeter of each floor to prevent the migration of flames up the side of the building. Firestop material is incorporated into the hollow area between the floor slab and curtain wall to create contained space at each story. Knock-out glazing panels made from tempered glass allow relatively safe emergency access in the event of a fire.

Acoustics

Laminated and insulating glass provide some measure of noise reduction, as does airtight construction. Sound-attenuating infill at spandrel areas may also help to dampen outside noise.

Light

Glazing replacement is expensive, but so is the high cost of running heating and cooling equipment overtime to combat solar heat gain. Poorly designed windows can make looking at a computer monitor difficult, and daylighting can hardly realize energy savings when glare results in drawn blinds and daytime lights. Generally speaking, *Visible Light Transmittance (VLT)* ratings of about 40 out of 100 help cut glare and restrict visibility from the exterior, without compromising occupants' views. Once VLT reaches about 70, however, the tinted glass becomes the primary focal point, diminishing visual access to the outside. The right glazing provides ample views, sufficient—but not excessive—natural light, and comfortable indoor temperatures.

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representative projects



Curtain Wall Rehabilitation

Glass curtain wall systems are subject to a host of typical problems. They can also fall prey to difficult-to-diagnose issues intrinsic to the building system and situation. That's where we come in. Hoffmann Architects' design professionals have the experience to accurately identify causes of curtain wall distress and to develop appropriate rehabilitation strategies.

We have developed curtain wall solutions for diverse structures, including:

Telcordia Technologies Headquarters

Piscataway, New Jersey
Curtain Wall Thermal Performance Consultation

300 George Street

New Haven, Connecticut
Glass Curtain Wall Rehabilitation



▲ **The Biltmore** in Stamford, Connecticut.
Glass Curtain Wall Rehabilitation Design.

Crystal City Office Complexes

Arlington, Virginia
Water Infiltration Remediation

MasterCard Headquarters

Purchase, New York
Glass/Travertine Curtain Wall Rehabilitation

Yale-New Haven Hospital

55 Park Street Laboratory
New Haven, Connecticut
Consultation for New Curtain Wall Construction

Stony Brook University Medical Center

Stony Brook, New York
Glass Curtain Wall Rehabilitation

Roger Ludlowe Middle School

Fairfield, Connecticut
Glass/Aluminum Panel Curtain Wall Repair

Alexander Centre

Princeton, New Jersey
Glass/Concrete Curtain Wall Rehabilitation

The George Washington University Elliott School of International Affairs

Washington, District of Columbia
Design Review for New Curtain Wall Construction

Bertelsmann Building 1540 Broadway

New York, New York
Glass Curtain Wall Repair

Pond View Corporate Center

Farmington, Connecticut
Granite/Glass/Glazed Brick Curtain Wall Rehabilitation



▲ **Edward J. Minskoff Equities at 590 Madison Avenue** in New York, New York.
Glass/Granite Curtain Wall Repair.

Kean University, Willis Hall

Union, New Jersey
Curtain Wall Replacement Design

Building Services Employees International Union Building 101 Avenue of the Americas

New York, New York
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Aesthetics

The most subjective metric, appearance, may also be the most persuasive when curtain wall replacement is under consideration. Changes in glazing, such as replacing non-reflective glazing with reflective glass, can have a dramatic impact on the building aesthetic. For owners wishing to maintain the current facade appearance while improving performance, replacement glass selection should consider existing sightlines, frame profiles, and glass properties.

Extending the Life of Glass Curtain Walls

Glazed curtain walls offer unparalleled design options, panoramic views, and

the flexibility to integrate with other types of facade systems. They also have their shortcomings. To achieve optimal curtain wall performance, identify emerging problems and take swift corrective action. Respond promptly to leaks, clouded glass, deflection, and other signs of wear, as these can be difficult and expensive to remedy if allowed to proliferate. Gasket and sealant replacement, generally every ten to fifteen years, should be part of a planned maintenance program. Through good design practices and routine upkeep, building owners and managers can realize improved curtain wall durability, for a system that is serviceable and attractive for many years to come. ■

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