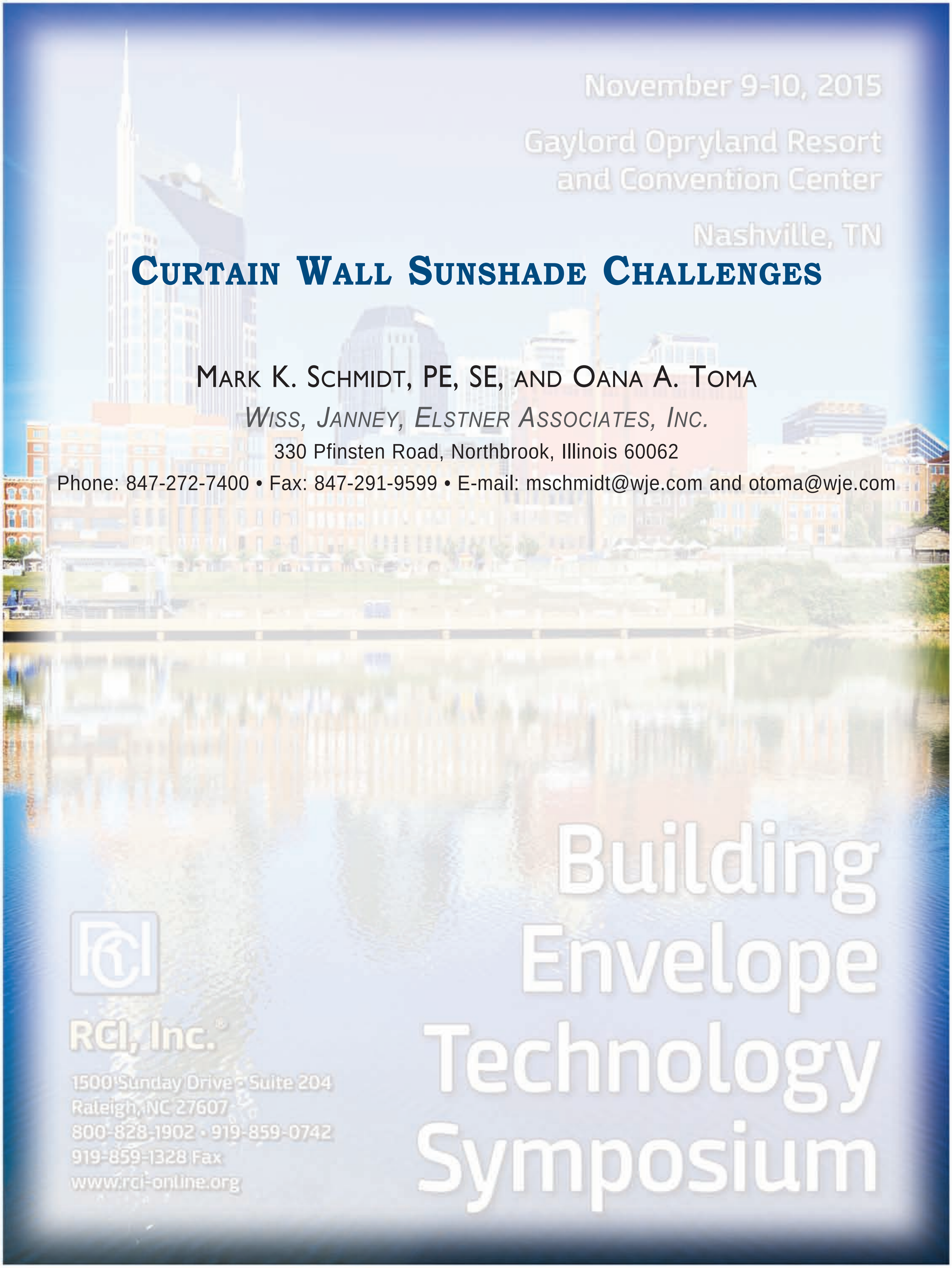
Curtain Wall Sunshade Challenges

Mark K. Schmidt, PE, SE, and Oana A. Toma

Wiss, Janney, Elstner Associates, Inc.

330 Pfinsten Road, Northbrook, Illinois 60062

Phone: 847-272-7400 • Fax: 847-291-9599 • E-mail: mschmidt@wje.com and otoma@wje.com



ABSTRACT

In the building design process, façades (and, especially, façade appurtenances) are generally given less in-depth consideration than main structural systems. Based on several related investigations, it has become evident that sunshade elements can be challenging to design and install, particularly in harsh climates. Failures due to inadequate design or installation may pose structural or life-safety concerns.

The authors will present two case studies that involve the use of inappropriate structural connection details (e.g., snap-on pieces and hooks) and failures resulting from typical seasonal loading. The cases highlight the difficulties in selecting proper design loads, as model building codes are typically quiet regarding such appurtenances.

SPEAKERS

Mark K. Schmidt, PE, SE — Wiss, Janney, Elstner Associates, Inc.

Since joining Wiss, Janney, Elstner Associates in 1982, MARK SCHMIDT has performed hundreds of building envelope investigations addressing operational concerns (such as water infiltration and corrosion), safety concerns (such as glass breakage, anchorage, and component failure), and aesthetic concerns (such as finish or surface degradation). He has led investigations of aluminum-framed curtain walls, architectural precast concrete panels, thin-stone veneers, stone and brick masonry, terra cotta, door and window assemblies, skylights, composite panels, mosaic tile systems, EIFS, and stucco systems. Schmidt has authored over 25 papers and given over 20 related presentations.

Oana A. Toma — Wiss, Janney, Elstner Associates, Inc.

OANA TOMA joined Wiss, Janney, Elstner Associates, Inc. in 2013. Since then, she has been involved in the field investigation, evaluation, and rehabilitation of a wide range of structures, including reinforced concrete and steel buildings, bridges, parking structures, foundations, and power-generating stations. She has conducted concrete durability testing in the field, materials evaluation in the laboratory, and service life analyses. Toma has also participated in several building envelope evaluations ranging from routine inspection to failure investigation of structural and nonstructural façade components, including heavy involvement in one of the sunshade failure projects being presented.

Curtain Wall Sunshade Challenges

ABSTRACT

In the building design process, façades (and, especially, façade appurtenances) are generally given less in-depth consideration than main structural systems. Through the authors' numerous investigations of structural-related deficiencies of building façades, it has become evident that sunshade elements can be challenging to design and install, particularly in harsh climates. Failures due to inadequate design or installation can pose structural or life-safety concerns.

Information related to the field investigation and analysis of aluminum sunshade failures from two case histories are presented herein. These cases involved the use of problematic structural connection details (e.g., snap-on components and hooks) that failed under typical seasonal loading. The cases also highlight the difficulties in selecting proper design loads for sunshades, as model building codes are typically silent regarding such appurtenances. It is therefore advisable to carefully detail and—when necessary—engage an experienced professional to review significant sunshade designs and modifications.

BACKGROUND

Model building codes and code references address the design of a wide range of structures and structural elements. Occasionally, unconventional elements may warrant additional literature research to aid in the design process. Although sunshades are not uncommon in current architectural design practice, even literature on curtain walls (with which sunshades are often integrated) and related elements lacks complete and consistent guidance on how to design these appurtenances.

Manufacturers of pre-engineered sunshade products offer limited technical literature, at best providing some general design calculations or load tables. They rarely indicate what design loads need to be considered for project-specific building sites and sunshade configurations. Presumably, their sunshades are designed somewhat conservatively to allow for installation on a wide range of projects with different loading criteria. However, these loads may not be sufficient in harsher climates.

When a building design calls for sunshades on the façade, design professionals should consider all relevant design loadings, including wind, snow, and ice. (It should be noted that the design of curtain walls and related appurtenances is often delegated by the design architect to a design build entity.) Though the application of design loads on these appurtenances would appear to be elementary, the lack of guidance available within the industry could lead designers to use inappropriate methodologies for determining design loads. Some of the approaches may oversimplify the design conditions, and it is possible that the resulting sunshade designs could be inadequate. In some cases, the structural design of sunshades and other appurtenances, which are commonly added to the building façade for aesthetics or energy savings, is overlooked altogether.

CASE STUDIES

The authors have investigated two cases of sunshade failures in recent years. These cases highlight the challenges involved in the design and construction of sunshades and the importance of proper review at all stages.

Northeastern Region Building

The subject Northeastern Region building is a three-story structure clad with strip window systems and integral sunshades. It was approximately two years old at the time of investigation and located more than 30 miles from the ocean. A cross section of a typical sunshade is shown in *Figure 1*. The sunshades are two windows wide, spanning across an intermediate vertical mullion. Each sunshade is comprised of three aluminum components that are joined by snap connections (hereafter termed "component snap connections"). The three-component, shop-assembled sunshade is attached to two horizontal aluminum pressure plates—one along each window opening—via a snap connection (hereafter termed "pressure plate snap connection"). At each end of each pressure plate, there are screws installed in countersunk holes at the top and bottom of the sunshade in an effort to prevent disengagement of the pressure-plate snap connection at these locations, as shown in *Figure 1*. Each pressure plate is attached to a horizontal aluminum mullion with two rows of stainless-steel screws, spaced at 12 in. on center, which engage dual screw chases in the mullion (hereafter termed "pressure-plate screw connection").

During mid-winter, portions of seven sunshades fell from the building: six failed at component snap connections, and one at a pressure-plate screw connection. In addition, one sunshade was observed to be hanging precariously from its pressure-plate snap connection. Two of the first-floor sunshades may have been impacted by falling sunshades from above, which could have contributed to the failure of their snap connections. At the time of failure, it appears that approximately ½ ft. of snow

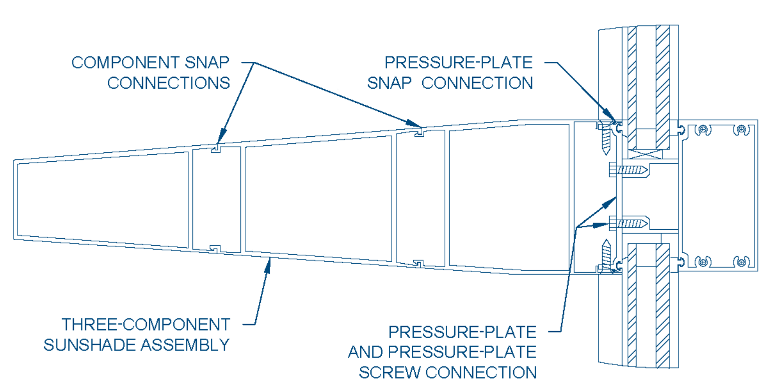


Figure 1 – Typical sunshade cross section.

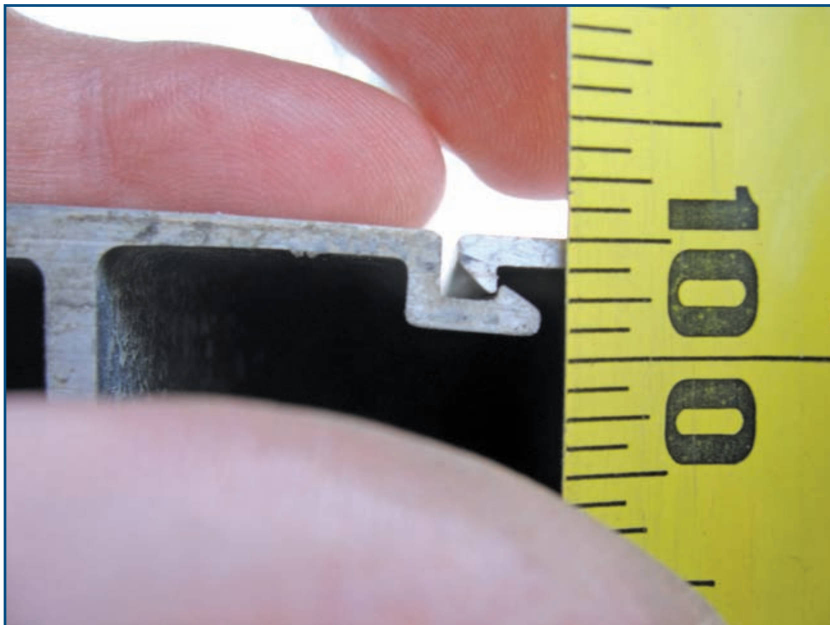


Figure 2 – Approximately 1/32-in. engagement of component snap connection.

Figure 3 – Upper pressure-plate snap connection with avenues for water penetration through open ends and along gasket between pressure plate and glass.

had accumulated on significant portions of the sunshades.

Inspections of intact sunshades revealed limited engagement of component snap connections, as shown in *Figure 2*. Avenues for water penetration into the component snap connections, as well as the pressure plate snap connections (*Figure 3*), were evident. Though these conditions were installed in conformance with the shop drawings, trapped water could freeze and cause localized disengagement of the snap connections. At one sunshade with failed component-snap connections, the pressure-plate snap connection was also partially disengaged, and the remaining sunshade component was easily disconnected from the pressure plate. Dust and small debris were observed at the disconnected pressure-plate snap connection, as shown in *Figure 4*. Similar conditions were noted at other sunshade-snap connections.

At the sunshade where failure occurred at the pressure-plate screw connection, the tapped aluminum of the screw chase was stripped (*Figure 5*). Upon disassembly of additional sunshades, it was noted that the screw chase was stripped at several screw locations. During removal and reinstallation of the pressure plates, it was determined that these con-

Figure 4 – Dust/debris within disassembled snap connection.

Figure 5 – Stripped aluminum screw chase at failed pressure-plate screw connection.

Figure 6 – Typical engagement of pressure-plate screw in chase (pressure plate not shown).

nections could be easily stripped due to the relatively shallow engagement of the pressure-plate screws and the somewhat oversized screw chase (*Figure 6*). Corrosion of the aluminum screw chase was noted at nearly all of the upper screw sites at the sunshade with the pressure-plate screw connection failure. Many stainless-steel pressure-plate screw sites exhibited similar corrosion; *Figure 7* illustrates a location with relatively severe corrosion.

The detrimental effects of galvanic corrosion on the pullout strength of these types of screw connections has been documented by Cui and Schmidt.[1] For severe corrosion conditions, the estimated strength loss after more than 20 years of exposure was approximately 30%. It is widely known that the presence of crevices and a more noble metal can result in severe localized corrosion of a metal that would otherwise remain passive. The horizontal aluminum mullions in this curtain wall system had documented characteristics that promoted corrosion: water infiltration, crevices at the interface between screws and screw chases, and presence of a more noble stainless-steel screw material (as compared to the base aluminum).

Review of pertinent specification sections indicated that the contractor's curtain wall design (including sunshades) was to accommodate construction tolerances, deflection of building structural members, and clearances. Specifically prohibited was the loosening, weakening, or fracturing of fasteners or system components. There was no design documentation related to calculations or tests for the capacity of the sunshade snap connections.

To verify the design, an engineering firm engaged by the contractor assumed various sunshade design loads, including a concentrated live load, a snow/ice load, and a wind load. The estimated static loads at the time of failure were significantly less than the assumed design loads. The calculations assumed that the stainless-steel pressure

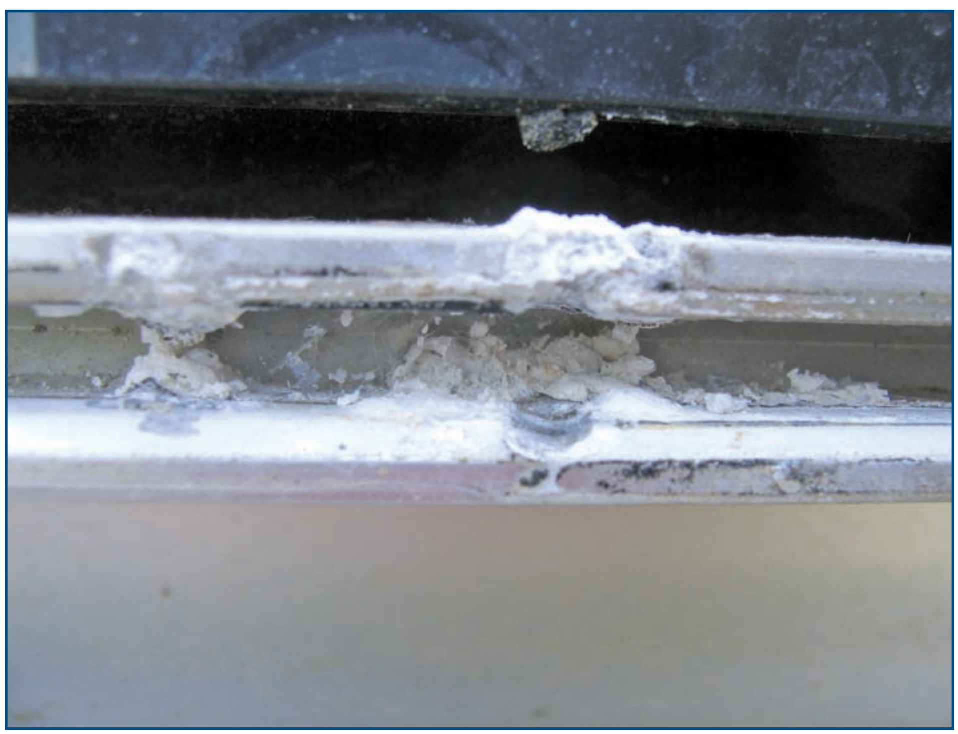


Figure 7 – Severe corrosion of aluminum screw chase.

plate screws were engaged approximately ½ in. into the screw chase. The beveled edges and oversize of the screw chase and the tapered end of the screw were not considered in estimating the depth of engagement. The contractor's engineer determined that there was a factor of safety of approximately 2.5 against the calculated design pullout load, which was based on the critical snow/ice load criteria.

The authors performed independent calculations on the pressure-plate screw connection, considering the effects of actual screw engagement in the screw chase, the oversized screw chase, and potential effects of aluminum corrosion at the screw sites. None of the screws' sites were assumed to be stripped. The resulting screw pullout capacity was less than 50% of that calculated by the contractor's engineer. The corresponding factor of safety against pullout under design loads was significantly less than a commonly used industry standard of 3.0.[2] However, the reduced capacity was still sufficient to resist the estimated in-situ loads at the time of failure. It therefore appears that conditions at the one sunshade failure that occurred at the pressure-plate screw connection included several stripped screw connections or a more substantial loss in capacity due to corrosion within the screw chase, or both.

The most likely cause of failure for most of the sunshades was the partial disengagement of snap connections, which failed under the sunshade self-weight and minimal snow accumulation. Factors contributing to this disengagement may have included moisture (freeze-thaw) and thermal cycles, incomplete engagement during initial installation, die tolerances, differential movements between the sunshade and the supporting strip-window framing, and potential impact loads from small amounts of falling snow/ice. The fact that the failure occurred during conditions favorable to freezing and thawing suggests that expansive forces of ice within the snap connections played a significant role.

The reliance on snap connections for this particular sunshade design resulted in an inherent vulnerability to environmental conditions. Normal thermal and moisture cycles have been known to cause disengagement of snap-type connections on other building façades. While these connections are used prolifically in curtain walls, the supported components are typically smaller than the subject sunshades. Curtain wall appurtenances that extend considerably from the face of the building resist significant structural loads; therefore, they present increased risks of snap connection disengagement and should be used with caution.

To remediate the connection deficiencies of the existing sunshades (vulnerable snap connections and stripped/corroding pressure plate screw connections), additional connections and anchorages were installed and load-tested prior to widespread application on the façade.

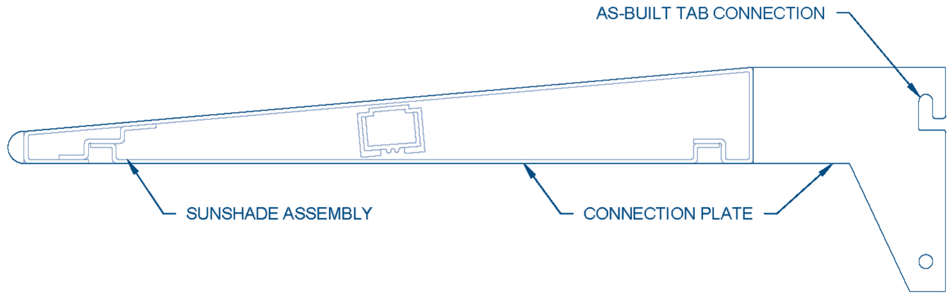


Figure 8 – Geometry of sunshade connection plate as observed in field. Shop drawings indicated top-bolted connection was intended to be a standard hole, not a tab.

Midwestern Region Building

The Midwestern Region building is a one-story steel-framed building, approximately 30 ft. tall, with glass and aluminum curtain walls on all exterior faces. The building was constructed approximately 12 years prior to the time of investigation. Sunshades are installed along most of the length of the west façade. There are several horizontal rows of flat-plate sunshades, comprised of formed aluminum panels that extend from the face of the building. The panels are supported by connection plates extending from the building (*Figure 8*). The connection plates are laser-cut aluminum plates that fit into a slot in the vertical mullions of the curtain wall and are connected to the mullion with two vertically spaced bolts. According to the shop drawings, both bolt connections were to be made through standard holes in the plates.

After a large snowstorm during mid-winter, several consecutive panels of the uppermost row of sunshades collapsed (*Figure 9*). Five connection plates were observed to be fractured and rotated out of position. To allow for a more detailed examination

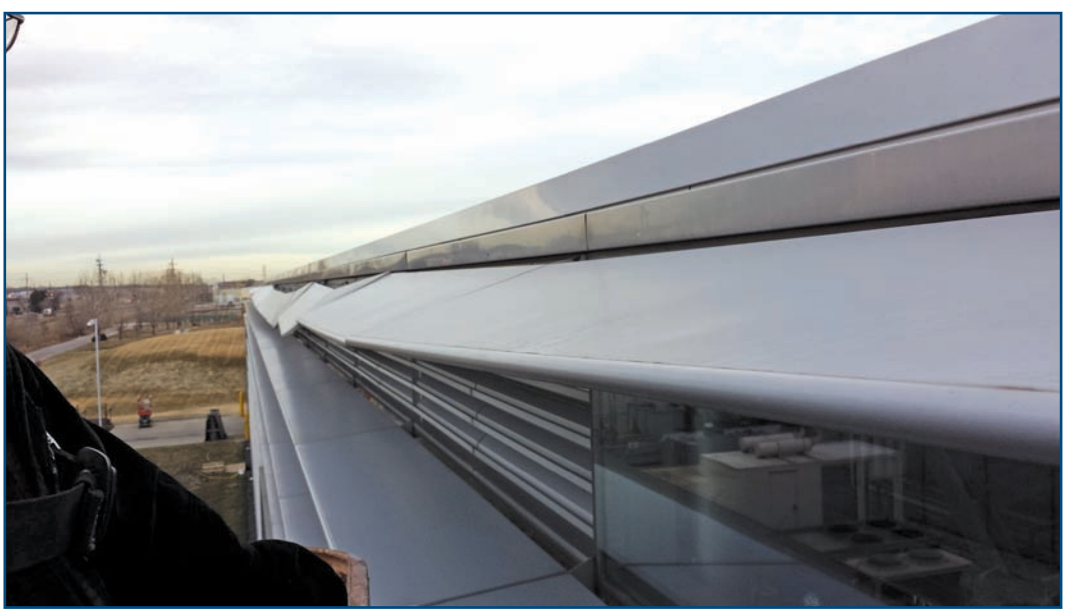


Figure 9 – Failed top row of sunshades.

of the connection, a contractor removed two adjacent sunshade panels, as well as the failed connection plate between them. A discrepancy was noted between the shop drawing connection configuration and the installed connections. Rather than a standard hole at the top of the connection plate where it bolted into the mullion (as indicated in the shop drawing detail), a tab-type connection was found, as shown in *Figure 8* and *Figure 10*. At the failed connections, this tab was found to be fractured. This condition may have been a change indicated by the contractor to streamline installation; however, no related documentation was found. Review of such post-design modifications is often overlooked.

With the above-described preliminary understanding of the failure mechanism, the sealants at the connection plate-to-building interface were inspected for evidence of movement at all other connections on the same wall. At all top-row connections, at least some stretching and/or tearing of the sealant was observed, indicating movement and possibly early stages of failure at the connections. As a result of these findings, all affected sunshades were immediately removed.

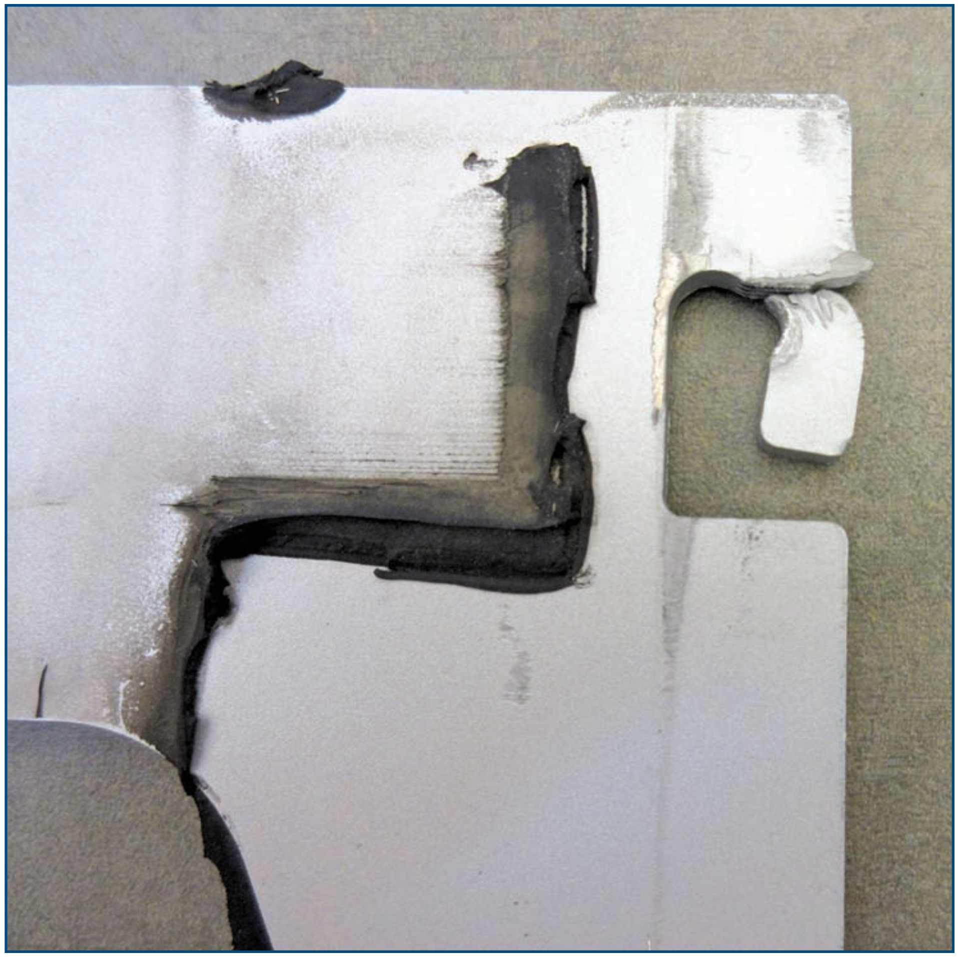


Figure 10 – Failed tab connection at top bolt hole of sunshade connection plate.

No original design calculations could be located for the sunshades. Therefore, a limited structural analysis of the sunshades was performed to estimate the demand on the sunshades and their structural capacity, accounting for any observed discrepancies between the shop drawings and as-built conditions. The connection plates were analyzed to determine whether they could adequately resist design loads required by the code in force at the time of construction.

A code reference and literature search was conducted to determine the best approach for determining design loads for this sunshade installation, but nothing directly applicable to this design was found. The sunshades in the failed top row were located just below the roof level, essentially acting as a roof overhang. Therefore, common overhang design loads were used to analyze the failed sunshades.

The selected loads consisted of self-weight, snow, and ice. Following the roof overhang comparison, the full balanced roof snow load was applied. In some load combinations, a dense layer of ice on the top surface of the sunshades was also included. Wind loading on roof overhangs is typically considered to act upwards. Only gravity loads were considered for the sunshades, since inclusion of wind loading created a less critical demand. Under combinations of these design loads, structural analysis indicated that the bolted tab connection was grossly overstressed relative to its design capacity at the observed failure plane. Under in-situ loads estimated from weather reports at the presumed time of failure, it was confirmed that the failure of the connection tab was predictable.

As indicated by the shop drawings, the top bolt in the connection plates was originally intended to be installed in a standard hole in the plate. A standard hole would have had a significantly greater shear capacity than the installed tab connection due to an increase in the number of shear planes carrying the load (*Figure 11*). Structural analysis of the as-designed condition indicated that if the connection plate had been fabricated as shown in the shop drawings, it would still have been moderately but not grossly overstressed under applied design loads. Under estimated in-situ loading, though, it is not likely that the connection as shown on the shop drawings would have failed. It is unknown when the hole-to-tab modification occurred, but it appears likely that the change was not appropriately reviewed; in this situation, a proper review of a design change could have potentially prevented a failure.

As a result of the failure of the top row of sunshades, the client wished to have the similarly designed lower rows of sunshades evaluated as well. The lower sunshades were a slightly different shape, but had approximately the same design capacity. The rows of sunshades were spaced only a few feet apart vertically. This close spacing would likely result in different loading conditions

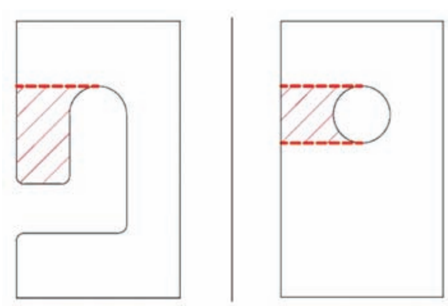


Figure 11 – Shear planes for tab and standard hole-connection details.

for the lower rows, due to both the effects of shielding by the row of sunshades immediately above and the potential accumulation of snow drifts along the face of the building. Therefore, the lower rows were less straightforward to analyze, as no ideal comparison for loading (like a roof overhang) exists in the code references. The codes and recognized standards for structural loads do not provide any guidance regarding how to calculate design loads on such shielded façade elements, particularly as they relate to snow and wind.

As an initial check, the balanced snow depth corresponding to the maximum design capacity of the sunshades was determined. It was found that the sunshade connection plates could only support a small fraction of the roof-level design snow loads. Without further analysis from data provided by experts experienced in snow accumulation and wind effects on façade appurtenances, the likelihood of a design overstress condition in the lower rows of sunshades appeared probable.

The design challenges faced in this case study ultimately led to a partial failure of the sunshade system and questionable reliability elsewhere. Assuming design calculations were performed, it appears likely that the selected loads were inadequate for the harsh Midwestern climate. Also, the undocumented modification to the connection plate aggravated the situation by significantly reducing the load-carrying capacity. Even with the lack of guidance on sunshade designs, it seems reasonable that the failure could have been prevented through proper review by an experienced design professional.

CONCLUSIONS

As shown in the two case histories, sunshade installations can be adversely affected by vulnerable or improperly designed connections. Consequently, the following design recommendations are offered to help ensure long-term serviceability of sunshade installations:

- Insist on a thorough structural design for sunshade systems, including accompanying structural calculations, performed by an experienced professional. For significant installations, the assistance of specialty consulting engineers (utilizing physical testing or analytical techniques) should be considered to determine appropriate climatic design loadings, so that the design is neither overly simplistic nor overly conservative.
- Vigilantly enforce a proper structural review of any proposed design or installation changes.
- Cautiously use screw connections in pullout, particularly those in screw chases. Experience has shown significant variability in capacity sizing of the screw and chase, actual thread engagement of the screw within the chase, and effects of aluminum corrosion from dissimilar metal contact (i.e., galvanic corrosion).
- Consider alternatives to snap connections for attaching curtain wall appurtenances that extend considerably from the face of the building and resist significant structural loads, especially in harsh climates.

REFERENCES

1. F. Cui and M. Schmidt, "Corrosion Assessment of an Aluminum-Framed Curtain Wall." 2007 RCI Symposium on Building Envelope Technology, November 2007.
2. AAMA TIR-A9-1991 (2000 Addendum) Metal Curtain Wall Fasteners Addendum, American Architectural Manufacturers Association, Schaumburg, Illinois, 2001, page 1.