The Florida Catastrophic Storm Risk Management Center

Final Report

Testing of Connections to Improve Hurricane Resistance of Aluminum Structures

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Florida Catastrophic Storm Risk Management Center

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ABSTRACT

Aluminum screen enclosures suffer from significant insurance losses due to hurricane winds. The damaged screen enclosures frequently produce airborne debris, which can often lead to additional damage on the host structure and nearby structures. Most commonly, a screen enclosure fails due to insufficient connection performance. The objective of the research is to improve hurricane-resistance of aluminum screen enclosures by improving the performance of these connections.

The report begins by summarizing experimental investigations on various connections. Due to the extensive variety of connection designs used by contractors across Florida, several connection specimens were tested and analyzed to provide the best performing and most cost efficient results. The connection components under investigation mainly included angle size, screw layout, and screw size. These components were monitored with the overall goal of optimizing the hardware combination. Each specimen was tested against windward and uplift forces using an MTS machine capable of delivering axial forces to the specimens.

After identifying the attributes of better-performing connections, cost-benefit analyses were conducted. Fragility curves were constructed to determine the probability of connection failure. The fragility curves were combined with the probability of the wind to estimate the cost-benefit.

The conclusions obtained from testing will provide valuable information to screen enclosure designers and contractors who hope to get clarification on the ambiguous range of connections used throughout Florida. Since little tangible research has been conducted on the strength of screen enclosure connections, the insight provided by this research could prove useful to the screen enclosure industry as well as insurance industry.
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ALUMINUM SCREEN ENCLOSURES

Exterior structures are common throughout Florida. Among various types of exterior structures, the focus of this report is aluminum screen enclosures (Figure 1). Damaged screen enclosures typically harm the host structure at attachment points and provide a source of wind borne debris upon failure. In addition, the average total value of exterior structures is 10.3% of the entire home value so damaged screen enclosures inevitably produce significant insurance losses on a yearly basis [1]. Screen enclosure failures can be linked to inadequate engineering design approaches, building department reviews, and construction quality [1]. Therefore, steps developed to increase design standards and educational requirements would greatly benefit the screened enclosure industry as well as the insurance companies experiencing significant annual insurance losses. The potential reduction in loss costs for screen enclosures properly designed and built to newly developed standards is estimated to more than a factor of 4 to 5 [1].

Figure 1. An example aluminum screen enclosure (photo provided by American Discount Aluminum)

For aluminum screen enclosures, many design guides exist throughout the state of Florida. To provide an overview of the elements in a design guide, screen enclosure chapter of the AAF

**Roof Type:** The AAF guide offers several styles of roofs. The list of roof styles include flat, gable, hip, mansard, transverse gable, and dome. Next to the roof style details, references to allowable span tables corresponding to each roof style are listed.

**Allowable Span Tables:** Beam allowable spans are developed based on the roof style, exposure category, wind speed, wall height, roof pitch, and overall length of beam. The design wind pressures are based on Table 2002.4 of Florida Building Code [3].

**Connection Details:** The most relevant section of the screen enclosure chapter to the research is the connection details, which include column to foundation, screen eave to longitudinal and side walls, purlin to beam, and gutter to host connections. Each detail involves specifications for sheet metal screw size and angle size. Multiple options of connections add versatility of the AAF guide. For example, the gutter to host connection is detailed using five separate representations based on common fascia configurations.

**Bracing Strategies:** Another important aspect of the screen enclosure is the bracing. Bracing strategies are vital in the performance of a screen enclosure, but they are not within the scope of this research.
PLAN AND SETUP FOR CONNECTION TESTING

Specimen Specifications

Based on the feedback from industry experts, aluminum-to-host (house) connections were selected as the main focus of the research (Figure 2). The aluminum-to-host connections are critical in the performance of the screen enclosures.

![Host Structure](image)

**Figure 2. Connections investigated in this research**

Each specimen was modeled with a gutter and structural beam in addition to its connection components. The gutter and beam followed full-scale dimensions but the length was chosen to accommodate the test apparatus’ size constraints. The specimen components are full size so the behavior of the connection is accurately represented. However, the magnitude of the loading should only be associated with component testing due to the short length of the specimen.
Figure 3 and Figure 4 show the drawings of the Specimen 1. All specimens were comprised of a 3 ft long gutter with a 2x8 beam member connected perpendicularly. A 2x8 wooden beam was fixed to the back of the gutter of each specimen using a lag screw or sheet metal screw. The wooden 2x8 represents the roof fascia usually connected to the rest of the roofing system. The gutter and beam sizes remained constant throughout the specimen design process but the connection components varied substantially. Table 1 lists the complete list of specimens.
investigated in this research. For the drawings of all specimens, refer to the thesis by Schellhammer [4].

Table 1. List of specimens

<table>
<thead>
<tr>
<th>Specimen Index</th>
<th>Angle Size (W x D x L)</th>
<th>Angle Thickness (in)</th>
<th>Lag Screw</th>
<th>Screw Size S.M.S</th>
<th>No. of Screws</th>
<th>Screen Attachment</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2x2</td>
<td>1/8</td>
<td>Yes</td>
<td>#14</td>
<td>4</td>
<td>No</td>
</tr>
<tr>
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<td>2x2</td>
<td>1/8</td>
<td>No</td>
<td>#14</td>
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<td>3</td>
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<td>1/8</td>
<td>Yes</td>
<td>#14</td>
<td>6</td>
<td>No</td>
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<tr>
<td>4</td>
<td>4x4</td>
<td>1/8</td>
<td>No</td>
<td>#14</td>
<td>6</td>
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<td>5</td>
<td>(2) 4x4x4</td>
<td>1/8</td>
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<td>#14</td>
<td>(2) 2</td>
<td>No</td>
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<tr>
<td>6</td>
<td>(2) 4x4x4</td>
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<td>(2) 2</td>
<td>No</td>
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<tr>
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<td>1/8</td>
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<td>1x1</td>
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<tr>
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<td>(2) 2x2x2</td>
<td>1/8</td>
<td>Yes</td>
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<tr>
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<td>2x2</td>
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<td>#8</td>
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<td>#14</td>
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<td>1/4</td>
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<td>#14</td>
<td>4</td>
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<tr>
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<tr>
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<td>#14</td>
<td>(2) 2</td>
<td>Yes</td>
</tr>
<tr>
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<td>3x3</td>
<td>1/4</td>
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<td>#14</td>
<td>4</td>
<td>Yes</td>
</tr>
<tr>
<td>20</td>
<td>4x4</td>
<td>1/8</td>
<td>Yes</td>
<td>#4</td>
<td>6</td>
<td>No</td>
</tr>
</tbody>
</table>

Test Setup

The ultimate capacity of each specimen was tested for yield loading and “fatigue” type loading. Yield loading consisted of monotonically increasing the applied force until the failure of the connection. The fatigue loading followed procedure B of ASTM E-330 [5] section 11.3 which calls for 50% of the ultimate load to be applied to the specimen then removed. After the pre-load was issued the test was carried out identically to a normal yield test.

Although the loading mechanism described above is different from an actual hurricane loading, it will be very effective in comparing the capacity of various connections. The connections that show higher capacity generally will have better hurricane resistance. The large deformation
greater than Florida Building Code’s L/80 criterion in section 1613.1[3] is intended, so that the behavior of the connections at failure can be investigated.

Two major load cases on the connection are uplift and windward forces. Preliminary tests showed that the windward loading case was controlling. Therefore, the research focused on the windward loading case.

Figure 5 shows the test set up. A hydraulic MTS machine was used to deliver the windward forces. The MTS machine is capable of applying axial forces in the vertical direction therefore the specimens placed within the machine were situated in order to simulate the uplift and windward forces.

As shown in the figure, the gutter was fixed using two rods extending the longitudinal length of gutter with a plate fastened to the top. The plate keeps the gutter rigid and prevents any movement of the specimen other than the deflection of the beam.
The set up has accurate representation of the boundary conditions on the side of the host structure, which is assumed as completely fixed. Conversely, the free-end of the beam would result in lower capacity of the connections. In reality, the beam is supported by the aluminum structure, which provides stiffness. The component testing is not intended to obtain exact ultimate capacity of the connection, but to compare relatively the performance of various connections within the testing limits. The component testing enables us to compare a large number of specimens within limited time and budget.

Obtaining the data was accomplished using Labview 8.5.1. The NI 9237 data acquisition module records a voltage produced by a load cell and converts the voltage reading into poundage. The voltage reading was converted using a calibration equation built into the Labview acquisition module. The loads recorded for each run were presented over an arbitrary range of increments and then averaged to obtain accurate readings.
EXPERIMENTAL RESULTS

Definition of Failure

According to the load versus displacement graphs, a majority of specimens developed yield loads within the 100-140 lb range with some specimens yielding below the 100-140 lb range. For the sake of further analysis, such as the formation of fragility curves, the yield moment will serve as the main definition of failure. The yield moment consists of the yield force multiplied by the moment arm about the y-axis. Although yielding does not represent total failure it would render the connection extremely vulnerable to future wind storms.

Failure Mechanism

When load was applied to each specimen the failure mechanism showed similar patterns. During the beginning portion of the loading, the angle strength was diminished past its yield value. From that point forward the angle was deflected inward until the final deflection value fell between 0.25 to 0.5 inches. Accompanying the angle deflection was screw pullout. One benefit of the lag screw was its resistance to pullout opposed to the normal sheet metal screws. The particular specimens with receiving channels failed because of channel separation and block shear of the channels. Since the channels were thinner than the angle component the channels were more susceptible to shearing forces. Figure 6 and Figure 7 show sample photos of failure.

The specimens did not undergo complete failure in the component testing, i.e., the structural member was not removed from the connection entirely. However, the plastic deformation of the angle critically compromised the connection if tested further which the ASTM pre-load tests confirms. Therefore, in real application of the hurricane wind loading, these partially failed connections would likely fail completely.
Figure 6. Specimen 1 at failure

Figure 7. Specimen 1 at failure

**Data Interpretation**

The basic comparison between specimens takes place between the deflections at a given load and the yield moments. Figure 8 and Figure 9 show sample load-displacement curves of selected specimens. For the complete results, refer to the thesis by Schellhammer [4]. Slightly higher deflections readings were expected from tests subjected to a pre-loading. Pre-load tests showed an average of 14% reduction in ultimate strength.
Figure 8. Sample load-displacement curves

Figure 9. Sample load-displacement curves, comparison with pre-load specimens

Specimens 7, 13, 18, and 19 indicated higher yield moments and lower deflection readings at 120 lbs. Identifiable aspects of specimens 7, 18, and 19 are two separate angles and 3x3 angles with #14 sheet metal screws and a screen attachment extrusion providing additional support on the member sides. Comparing the components of the four highest and lowest performing connections shows the presence of a screen attachment extrusion and the angle thickness possess the greatest influence on the resistance of loads. Six specimens with a screen attachment extrusion have deflections lower than 3”, with the exception of specimen 8. Also, four specimens
with an angle thickness of $\frac{1}{4}''$ yield deflections lower than 2 3/8''. Another notable component is a 3x3 angle size. A 3x3 angle yields positive outcomes, however 3x3 angles lack aesthetics and may not be an appealing option for some screen enclosure construction. Other components such as angle dimensions, lag screw, and angle layout do not demonstrate the consistent performance as a screen attachment extrusion angle thickness. A combination of a screen attachment extrusion with a $\frac{1}{4}''$ thick angle would expectedly produce the most favorable results. Table 2 displays an approximate ranking of specimen connection performance along with the noteworthy components.

### Table 2. Ranking of specimens based on load to deflection ratios

<table>
<thead>
<tr>
<th>Rank</th>
<th>Specimen</th>
<th>Angle Size*</th>
<th>Screen Attachment</th>
<th>Angle Thickness</th>
<th>Screw Size</th>
<th>Lag Screw</th>
<th># Screws*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3x3 (2)</td>
<td>2x2</td>
<td>1/4''</td>
<td>1/8''</td>
<td>#14</td>
<td>6</td>
</tr>
<tr>
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<td>7</td>
<td>3x3</td>
<td>2x2</td>
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<td>2</td>
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<tr>
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<tr>
<td>4</td>
<td>13</td>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* If unmarked, the specimen uses a type not included in the table.

Although the number of screws does not critically affect the performance as long as more than 4 screws are used, the use of only 2 screws significantly lowers the performance. All 3 types of
connections that used 2 screws performed poorly. For the drawings of all specimens, refer to the thesis by Schellhammer [4].
FAILURE PROBABILITY ANALYSIS

Fragility Curves

Once a level of damage is selected for investigation, the fragility curve describes the probability the selected level of damage will be met or exceeded [6]. For the sake of this research yielding of the connection is assumed to be a damage percentage of 100%, which is used in constructing the fragility curves. We employed the following equation [7] to obtain the fragility curve using the mean and the standard deviation of yield moment.

$$F_R(V) = \Phi \left[ \frac{\ln(V/m)}{\zeta} \right]$$

where $V = $ wind speed, $m = $ median capacity for which average yield moment is used in this research, $\zeta = $ logarithmic standard deviation, approximately equal to the covariance ($\sigma/m$), and $\Phi[*] = $ standard normal probability integral.

Before constructing the fragility curve with respect to the wind speed, the fragility curve with respect to the moment capacity is constructed first. To quantify the effect of using a better connection vs. a poorer connection, the specimens are grouped as shown in Table 3. Due to the way the screen enclosures are constructed, there is a great variability in the types of connections. A connection used in the real construction may use the angles and screws summarized in Table 1, but the exact details of the construction is likely to be different from the ones tested above. The groups shown in Table 3 is a means to categorize a connection used in the real construction.

<table>
<thead>
<tr>
<th>Group number</th>
<th>Specimen types</th>
<th>Yield moment (yield-type test)</th>
<th>Yield moment (fatigue-type test)</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td>Mean Standard deviation</td>
<td>Mean Standard deviation</td>
</tr>
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<td>7, 9, 10, 13, 14, 18, 19</td>
<td>363.81 61.04</td>
<td>312.88 52.49</td>
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<tr>
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<td>1, 2, 3, 4, 5, 6, 12</td>
<td>232.38 70.05</td>
<td>207.22 60.24</td>
</tr>
<tr>
<td>3</td>
<td>8, 11, 15, 16, 17, 20</td>
<td>160.28 36.86</td>
<td>137.84 31.70</td>
</tr>
</tbody>
</table>
Group #1 consists of specimens constructed with a combination of (2) staggered 2x2 angles, 1/4” thick angles, 3x3 angles, and/or a screen attachment. Group #2 involved specimens with 1/8” thick angles, no screen attachment, and/or 2x2 angles. Group #3 specimens utilized 1/8” angle thickness and no screen attachment like Group #2, but used #8 or #6 screws instead. Once groups were established, mean and standard deviation of yield moment of each group was computed.
Figure 10 and Figure 11 show constructed fragility curves. As expected, fatigue-type test show higher failure probability for the same applied moment. In order to use these curves for failure probability analysis against high winds, they should be converted to the ones with respect to the wind speed. These curves are specific to certain type of connection, regardless of the shape of the structure they are used for. On the other hand, the fragility curve with respect to the wind speed is specific to certain structure.

Figure 12. Fragility curve in terms of wind speed (yield-type test)

Figure 13. Fragility curve in terms of wind speed (fatigue-type test)
In order to convert the fragility curves for moment to those for wind speed, RISA-3D analyses are conducted. The conversion is done for the structure shown in Figure 14. For example, the moment of 250 lbs-ft is obtained when the applied wind pressures for 140 mph. By repeating the analysis for various wind speeds, the fragility curves in terms of wind speed are obtained. For other structures, the conversion must be conducted again based on new analyses, and the curves shown in Figure 12 and Figure 13 must not be used.

![Figure 14. Model full scale enclosure for the failure probability analysis](image)

**Hurricane Wind Probability**

In addition to fragility curves, the hurricane hazard is needed for the probability of failure model. Weibull distribution is employed for estimating the probability of hurricane wind speed [7, 9, 10]. The two-parameter Weibull probability density function is given:

\[
P_v(V) = \frac{\alpha}{u} \left( \frac{V}{u} \right)^{\alpha-1} \exp \left[-\left(\frac{V}{u}\right)^\alpha\right]
\]

The Weibull PDF represents the annual wind speed probability. Parameters \(u\) and \(\alpha\) are site-specific. Using South Florida as an example, the corresponding Weibull parameters are \(\alpha = 1.769\) and \(\mu = 61.07\) [7]. Formulating \(P_v(V)\) using the established parameters produces the distribution shown in Figure 15.
Failure Probability Analysis

The probability of failure under range of possible hurricane winds is determined by combining fragility curve with PDF of hurricane wind speed [7]:

\[ P_f = \int F_R(V)P_v(V) dV \]  

(3)

where \( F_R(V) \) = the fragility of the structure represented by a fragility curve, and \( P_v(V) \) = probability density function for wind speed.

Using the curves shown in Figure 12, Figure 13, and Figure 15, the failure probability is calculated with \( dV = 10 \). Table 4 summarizes the result. The result follows the expected trend of weaker connections failing more often than stronger connections.

<table>
<thead>
<tr>
<th>Group number</th>
<th>( P_f ) for yield-type loading</th>
<th>( P_f ) for fatigue-type loading</th>
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<tr>
<td>1</td>
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<td>0.17386</td>
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COST-BENEFIT ANALYSIS

Format of Cost-Benefit Analysis

Insurability issues are a common problem regarding homes located in hurricane zones. The combination of hurricane frequency and susceptible screen enclosures leads to high insurance losses and replacement costs. In an effort to provide another aspect of connection benefit a financial analysis was conducted.

To simplify the financial analysis framework it is assumed that a single connection failure would lead to complete failure of a screen enclosure. Although this notion is conservative it is thought the failure of a host connection in particular would leave the entire structure more vulnerable than failure at another connection. Comparisons between the connection groups offer financial benefit in dollars regarding one group over the other. The main comparison tool is the probability of failure of each group determined in the previous section. Likewise, comparisons between each connection can be made but takes into account the discrepancies from connection to connection as opposed to comparing particular hardware components that offer better performance. In order to combat insurability issues the life cycle cost of improved connections must be minimized.

The main aspects controlling a life cycle analysis of a pool enclosure include:

- Initial cost of the pool enclosure
- Cost of improved or engineered components i.e. connections
- Repair and replacement costs after enclosure failure

Just because a connection or connection component yields higher performance does not mean it is financially viable. It is important to balance financial risk with performance based risk. Improved connections involved at least some increased initial costs whether they come from the use of unfamiliar materials or new construction practices. For simplicity, annual maintenance costs are excluded from this financial analysis. In addition, it is assumed that insurance costs will be directly related to expected losses. The expected losses refer to the probability of enclosure
failure so insurance loss costs should increase linearly with probability of failure. The following financial analysis will deliver a response to the financial practicability of improved connections.

Results

According to surveys of local companies specializing in pool enclosure construction the value of a typical aluminum screen enclosures is approximately $10,000. This value is representative of an enclosure with the dimensions of the model referenced in the previous section. The variety of customized enclosures around the state of Florida changes the value significantly but for the sake of this financial analysis the value of an enclosure is generalized.

The first step is to develop an annual loss of the enclosure. Since the assumption was made to associate connection failure with enclosure failure the annual loss can be found by the following equation:

\[ L_{AAL} = C_0 P_f \]  

(4)

where \( L_{AAL} \) = average annual loss (AAL), \( C_0 \) = initial enclosure value, and \( P_f \) = the failure probability from equation (3).

Therefore, the AAL for the Group 1 is $10,000 x 0.00269 = $27 while the AAL is $386 and $1,226 for Groups 2 and 3 respectively. The differences between the AAL of each group represent the preliminary financial benefit (B) of using Group 1 connections to either Group 2 or Group 3 and vice versa.

\[ B = L_{AAL} - L'_{AAL} \]  

(5)

where \( B \) = financial benefit, and \( L'_{AAL} \) = AAL of the engineered structure.

Table 5. Annual benefit of a connection group versus remaining groups

<table>
<thead>
<tr>
<th>Group</th>
<th>vs. 1</th>
<th>vs. 2</th>
<th>vs. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>359.20</td>
<td>1,198.60</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>–359.20</td>
<td></td>
<td>839.40</td>
</tr>
<tr>
<td>3</td>
<td>–1,198.60</td>
<td>–839.40</td>
<td></td>
</tr>
</tbody>
</table>
The columns in Table 5 represent the Group of connections used on the enclosure and the benefit seen when used over the Group located in the rows. Initially, using Group 1 connections over Group 3 yields almost $1,200 in annual benefit while Group 2 yields $840 when compared to Group 3. The next step is placing the preliminary benefit in a present value analysis assuming a life span of 1 year and 10 years. The lifespan of 1 year determines the value of benefit in reduced loses if the enclosure fails once in 1 year’s time. The lifespan of 10 years provides an extreme case where the structure fails every year for 10 years straight thus showing the long term effects of improved connections. The equation for present worth used is as follows:

\[ P = B \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right] \]  

(6)

where \( i \) = real discount rate, due to the use of real dollars in the equation, \( n = 1, 10 \) years, \( B \) = benefit from Table 5, and \( P \) = present value. For the purpose of this research \( i = 3\% \), which is often used for benefit-cost studies of natural hazard risk reduction.

| Table 6. Present Value of connection group versus remaining groups (\( n = 10 \)) |
|-----------------|--------|--------|--------|
| Group | vs. 1   | vs. 2   | vs. 3   |
| 1     | 3,064.05 | 10,224.30 |        |
| 2     | −3,064.05 |         | 7,160.25 |
| 3     | −10,224.30 | −7,160.25 |        |

Essentially, when \( n = 1 \) the present value is the same as the annual benefit but Table 6 shows almost $10,225 of total benefit over the course of 10 years for Group 1 connections compared to Group 3 and even $7,160 for Group 2 connections compared to Group 3. The initial costs involved with improved connections weighs heavily on whether or not using improved connections is feasible. After examining the values in Table 6, using Group 1 connections show substantial benefit over a 10 year period. When stacked up against the initial costs of using Group 1 connections, $10,225 would control and deliver favorable results.

**Overall Impact**

In summary, connections involving thicker angles, larger screws, screen attachment extrusions, and staggered angles lining the attachment extrusion provide advantages regarding performance and also offer effective financial benefit. However, adapting to improved connections by using
different practices and more material could be challenging due to the extensive variety of connection types. In addition, the client typically holds final say when it comes to the aesthetic aspects of the enclosure and having subtle features is generally more attractive. More material and bulkier connections could work against a client’s wishes despite the connection’s financial and performance benefit.

We also emphasize that the above illustrations are for a sample structure shown in Figure 14, with the assumption that when a connection fails, the entire structure fails during the hurricane event. The analysis also does not include complicated load-redistribution mechanism, which may cause other weaker connections fail even if the enclosure-to-host connection does not fail. The load-redistribution mechanism of the screen enclosure is complicated, and a generic answer to the effect of improving a connection is very difficult to obtain.

Therefore, the illustrations should be taken as a possible scenario, but not as a generic answer to the financial benefit of using certain type of connection in the screen enclosure. Such an answer requires much more comprehensive investigations than what is conducted in this study.
SUMMARY AND FUTURE RESEARCH

Summary

In this research, the aluminum-to-host connection was investigated by testing specimens with typical hardware including angles, sheet metal screws, and screen attachments. The main objective of testing was to determine the probability of connection failure and relating failure to the financial loss or benefit seen from using particular connection hardware.

Performance data was accumulated by applying load to 20 specimen types consisting of a variety of hardware configuration and recording deflection of the structural beam modeled along with the connection. The load versus deflection data allowed specimens to be ranked according to performance then analyzed to determine specific hardware that possess the greatest influence on strength.

Once testing was complete, fragility curves were constructed, and then the failure probability was analyzed. Also, a financial model comparing the benefit of one group of connections over another was developed using life cycle cost analysis.

According to the investigations, using improved hardware, such as thicker angles, larger sheet metal screws, or additional stiffeners on the host connection can drastically reduce probabilities of connection failure, which in turn leads to decreased financial losses.

We also emphasize that the illustrations provided in this report is specific to a model structure used in the study. Even for the same connection, the financial loss or benefit may be significantly different if it is used for a different structure.

Future Research

Research pertaining to screen enclosure host connections is practically non-existent to date so at the very least this research serves as an initial attempt to condense the assortment of connections
types. Further research should be conducted on specific connections used by contractors instead of relying on design guides. Connections used in the field would promote a more accurate representation of actual conditions. Ideally, field testing or wind tunnel testing of a full scale structure would serve as the next logical test using connections tested in this research.

In addition, bracing strategies significantly alter the load path of a full scale structure and subsequently diminish the loads taken by the host connection. Further investigation of various bracing types and placement would assist in strengthening the structure as a whole. The redistribution of loads over a full scale structure should be explored in order to explain this issue.
REFERENCES