Mitigation Techniques for Aluminum Pool Enclosure Connections in High Wind Speeds

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MITIGATION TECHNIQUES FOR ALUMINUM POOL ENCLOSURE CONNECTIONS IN HIGH WIND SPEEDS

By

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ABSTRACT

Aluminum pool enclosures consistently yield significant insurance losses due to damage suffered during hurricanes and strong windstorms. The damaged pool enclosures frequently produce airborne debris, which can often lead to additional damage on the host structure. For this reason, pool enclosures represent an important area of concern when it comes to mitigating overall structural damage caused by hurricanes and strong windstorms. Most commonly, a pool enclosure fails due to insufficient connection performance. Insufficient connection performance generally consists of screw pullout and/or other hardware failures. Improving the function of these aluminum connections can help alleviate pool enclosure failure and thus lessen the amount of insurance losses accumulated.

This research investigates different mitigation techniques involving the pool enclosure connection with the host structure. 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. In addition to continuous loading, fatigue loading was utilized to examine connection behavior once the connection was compromised and a load is re-applied. Load and corresponding displacement values were recorded during testing to provide comparable strength capacities for each specimen. In order to determine the probability of connection failure, fragility curves were constructed and interpreted then applied to a financial analysis to achieve benefit-cost ratios. The resulting financial and performance benefits serve as benchmarks for optimal connection configuration.

The conclusions obtained from testing will provide valuable information to pool 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 pool enclosure connection strength the insight provided by this research could prove useful to the pool enclosure industry.
CHAPTER 1

1. INTRODUCTION

1.1 Motivation for Research

Failure of aluminum screened pool enclosures pose a significant problem on a year to year basis due to the frequency and severity of failure. In contrast to host structures, the aluminum enclosures suffer the most damage during a strong wind storm and contribute to high insurance losses for the owner. Due to the desire to maintain an unobstructed open look, a majority of aluminum enclosures use slender beams, columns, and girts which leads to increased loads on connections, particularly the beam to host connection.

Aluminum pool enclosures are widely prevalent around the state of Florida. According to the field survey of selected towns [3], 30% of site-built homes have pool or patio enclosures. In conjunction with the previous statistic, properties with pool enclosures experience a 35% increase in claims compared to properties without pool enclosures. Consequently, pool enclosures are an area in need of structural improvement. Pool enclosures usually fail completely, meaning a damaged enclosure requires a full replacement. The majority of insurance losses and owner headaches stem from the need for a full replacement instead of just partial repairs. In order to limit these significant losses steps must be done to increase both the structural function and financial feasibility of the pool enclosures. While the entire pool enclosure presents several aspects in needed of mitigation, this report will only focus on the host connection. A mitigation approach will be proposed to help limit host connection failure at the same time maintaining its financial practicality.

1.2 Scope of the Research

Comprehensive research efforts conducted over the course of several years are required to address the multitude of problems posed aluminum structures. Since the research study was limited to less than a year, several meetings with knowledgeable members of the aluminum structure industry were held to determine the most critical aspect to investigate. The notable meeting attendees included
• Do Kim (President of Do Kim & Associates, former Chair of the Structural Technical Advisory Committee to the Florida Building Commission)
• David Miller (Chair of the Aluminum Association of Florida Technical Committee)
• Mike Driscoll (Driscoll Engineering, Inc.) in FAMU-FSU College of Engineering

Based on the meetings, it was decided that the research would focus on the host connections of aluminum screen enclosures. Failure of the host connection was identified as a primary area of concern due to the frequency in which host connection failures were observed in past hurricane damage studies. The behavior of these connections is uncertain, thus warranting research efforts. This report will mainly present experimental and analytical investigations of the behavior of host connections of screen enclosures.

1.3 Objectives

The main focus of the research is to test and compare the strength of host connection types consisting of various hardware combinations. The performance of the connection types will depend on the data produced by fragility curves and financial analysis. Hardware possessing the greatest influence on connection performance will be highlighted and verified to ensure financial feasibility. As a result, the data provided will hopefully serve as a starting point in understanding different mitigation steps needed to improve overall structural capabilities of screened pool enclosures. At the very least the research will offer some insight as to what hardware combinations will deliver better connection performance.
CHAPTER 2

2. LITERATURE REVIEW

2.1 Screen Enclosures
Exterior structures are common throughout Florida, averaging about one exterior structure per site-built home and almost three per manufactured home [3]. Due to the popularity of pools and patios accompanying homes in Florida, it can be assumed a majority of exterior structures are aluminum screened pool enclosures. These screened enclosures have widely varying building characteristics which increases vulnerability to hurricane damage. Damaged screened enclosures typically harm the host structure at attachment points and provide a source of wind borne debris upon failure [3]. In addition, the average total value of exterior structures is 10.3% of the entire home value so damaged screened enclosures inevitably produce significant insurance losses on a yearly basis [3]. Screened enclosure failures can be linked to inadequate engineering design approaches, building department reviews, and construction quality [3]. 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 screened enclosures properly designed and built to newly developed standards is estimated to more than a factor of 4 to 5 [3].

2.2 Vulnerability and Fragility Curves
In order to determine the probabilistic ability of a specific structure or structural component to resist hurricane force winds vulnerability and fragility curves are created. This section describes the differences between vulnerability and fragility curves as well as the function of each curve within the scope of the research. To develop each type of curve, the level of damage or damage state must be defined [6]. For example, damage can be considered as the percentage of overall structural damage. Therefore, at a certain wind speed, there will be a distribution of damage with the shape of a normal distribution function [6].
The vulnerability curve is a means of measuring the performance of the structure, and is generated from the location of the mean percent damage value from the damage distribution at each wind speed. Basically, the curve is generated by individual PDFs similar to Figure 1. Figure 2 depicts a graphical representation of a vulnerability curve [6].

Fragility analysis is a tool used to determine the reliability of a structural component or system [1], [6]. 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 a damage percentage of 100% will be used which still justifies the use of fragility curves. When dealing with fragility curves as a function of wind speed, the probability of failure
becomes more complicated. Wind is erratic in nature, therefore a function must be introduced to consider the probability of wind speed. Conceptually, the probability of failure under range of possible hurricane winds is determined by combining fragility curve with a hurricane hazard curve [1]:

\textbf{Equation 1: Probability of failure based on fragility and wind speed}

\begin{equation*}
P_{v}(V) = \text{probability density function for wind speed and will be discussed in Section 2.3.} \quad F_{R}(V) = \text{the fragility of the structure represented by a fragility curve. The fragility curve is formed by integrating the PDFs described in Figure 1 giving the shape illustrated in Figure 3 [6].}
\end{equation*}

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fragility_curve.png}
\caption{Example fragility curve}
\end{figure}

To summarize, the vulnerability curve shows the most likely mean damage that will occur to a given structure as a function of mean wind speed, while the fragility curve shows the probability of exceeding a specific level of damage as a function of wind speed [6]. For this research fragility curves will be employed with the level of damage being 100%.

\textbf{2.3 Hurricane Wind Probability}

In addition to fragility curves, the hurricane hazard is needed for the probability of failure model expressed in Equation 1. Research conducted by Batts et al. [10], and simulations of hurricanes by Vickery et al. [11] confirm that a Weibull distribution is appropriate for hurricane wind speed prediction [1]. The two-parameter Weibull probability density function is given:
Equation 2: Weibull PDF of wind speed probability

The Weibull PDF represents the annual wind speed distribution of South Florida. The wind speed is consistent with ASCE 7-05. Parameters $u$ and $\alpha$ are site-specific and can be determined from published wind speed maps [1], [10], [11]. Using South Florida as an example, the corresponding Weibull parameters are $u = 61.07$ and $\alpha = 1.769$ [11]. Formulating $P_v(V)$ using the established parameters produces the distribution shown in Figure 4.

![Weibull PDF $P_v(V)$](image)

**Figure 4: $P_v(V)$ versus wind speed for South Florida**

### 2.4 Financial Analysis

Screened enclosure failures saddle owners with replacement costs, higher insurance premiums, and higher property taxes and assessments. Incorporating the concepts put forth in Section 2.2 and Section 2.3 and the results presented in Section 6.3 supply the parameters needed for financial analysis of damaged screened enclosures. The main purpose of financial analysis is the balance risk versus cost. The tradeoff of designing structures to higher reliabilities with higher initial costs can be compared with designs that cost less, but fail more frequently [3]. Ultimately, the total insurance cost is associated with the likelihood of hurricane damage, which is the product of replacement costs and the probability of failure [3].
3. CURRENT DESIGN SPECIFICATIONS

3.1 Design Code Correlation

The size and function of an aluminum screen enclosure is generally dictated by design guides that are established by a range of organizations throughout the state of Florida. The purpose of this section is to discuss a particular design guide provided by the Aluminum Association of Florida (AAF 2007). The AAF Guide to Aluminum Construction in High Wind Speeds offers design specifications for several types of aluminum structures including carports, glass enclosures, utility sheds, and screen enclosures. Screen enclosures represent the primary focus of this report so the screen enclosure chapter of the AAF guide will be highlighted. Design elements in the screened enclosure chapter, such as roof style, structural member sizes, bracing options, foundation details, and connection details, are presented through variety of tables, graphs, and drawings.

3.2 Roof Type

The AAF guide offers isometric, elevation, and sectional details of several styles of roofs. The list of roof styles include flat, gable, hip, mansard, transverse gable, and dome. Limitless roofing styles and configurations are capable of being used for a screened enclosure, however AAF only provides the basic styles commonly used throughout Florida. Listed next to the roof style details are references to allowable span tables corresponding to each roof style.
3.3 Allowable Span Tables

At the end of the screen enclosure chapter allowable span tables are presented for key structural members. Beam allowable spans are developed based on the roof style, exposure category, wind speed, wall height, roof pitch, and overall length of beam. The exposure category and wind speed are necessary in selecting the correct design pressures conveniently provided by the Florida Building Code in table 2002.4 (ICC 2007). These design pressures are compatible with aluminum structures up to 30 feet.

After the roof style and design pressures are selected, the rise of the roof pitch is investigated at two different rise heights. The allowable spans are then developed for both rise heights at wall height 8, 11, and 14 feet. Lastly, the beam length parameter is listed from 5 feet to 8 feet at 6 inch intervals. Once the design parameters listed above are set, the allowable span values can be produced. Table 2 (Tables 101(c)8-14 taken from the AAF guide) show the allowable span
generally for sheet metal screw size and angle size. The sheet metal screw and angles sizes serve walls, purlin to beam, and gutter to host connections. Each detail involves specifications structure. Details of note include column to foundation, screen eave to longitudinal and side details. Connection details are offered in the AAF guide for the entire scope of the aluminum height of 4 feet maximum.

<table>
<thead>
<tr>
<th>Table 2: Allowable Span Tables from AAF 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable Spans for Mansard Beams with a Rise of 4 ft (Maximum)</td>
</tr>
<tr>
<td>Wall Height: 8 ft</td>
</tr>
<tr>
<td>Wind Zone: 120 mph Exposure B</td>
</tr>
<tr>
<td>Beam Spacing in Feet</td>
</tr>
<tr>
<td><strong>Self-Mating (or Lap) Beams</strong></td>
</tr>
<tr>
<td>2 X 6 X 0.050 X 0.120 SMB</td>
</tr>
<tr>
<td>2 X 7 X 0.055 X 0.120 SMB</td>
</tr>
<tr>
<td>2 X 8 X 0.072 X 0.224 SMB</td>
</tr>
<tr>
<td>2 X 9 X 0.082 X 0.306 SMB</td>
</tr>
<tr>
<td>2 X 10 X 0.092 X 0.374 SMB</td>
</tr>
</tbody>
</table>

| Table Span Note: where tabular span exceeds 40'-0", use 40'-0" |

| Allowable Spans for Mansard Beams with a Rise of 4 ft (Maximum) | Allowable Spans for Mansard Beams with a Rise of 4 ft (Maximum) |
| Wall Height: 11 ft | Wall Design Pressure: 4 psf |
| Wind Zone: 120 mph Exposure B | 15 psf |
| Beam Spacing in Feet | Table Span Note: where tabular span exceeds 40'-0", use 40'-0" |
| **Self-Mating (or Lap) Beams** | 5'-0" | 5'-6" | 6'-0" | 6'-6" | 7'-0" | 7'-6" | 8'-0" |
| 2 X 7 X 0.055 X 0.120 SMB | NA | NA | NA | NA | NA | NA | NA |
| 2 X 8 X 0.072 X 0.224 SMB | 27'-9" | 25'-3" | 22'-11" | 20'-10" | 18'-11" | 17'-1" | 15'-3" |
| 2 X 9 X 0.082 X 0.306 SMB | 30'-2" | 37'-5" | 35'-3" | 33'-3" | 31'-6" | 29'-7" | 27'-10" |
| 2 X 10 X 0.092 X 0.374 SMB | 50'-4" | 47'-6" | 45'-0" | 44'-3" | 42'-10" | 38'-11" | 37'-4" |

| Table Span Note: where tabular span exceeds 40'-0", use 40'-0" |

| Allowable Spans for Mansard Beams with a Rise of 4 ft (Maximum) | Allowable Spans for Mansard Beams with a Rise of 4 ft (Maximum) |
| Wall Height: 14 ft | Wall Design Pressure: 4 psf |
| Wind Zone: 120 mph Exposure B | 15 psf |
| Beam Spacing in Feet | Table Span Note: where tabular span exceeds 40'-0", use 40'-0" |
| **Self-Mating (or Lap) Beams** | 5'-0" | 5'-6" | 6'-0" | 6'-6" | 7'-0" | 7'-6" | 8'-0" |
| 2 X 8 X 0.072 X 0.224 SMB | 24'-6" | 21'-8" | 19'-1" | 16'-7" | 14'-2" | 11'-8" | 9'-1" |
| 2 X 9 X 0.082 X 0.306 SMB | 37'-9" | 35'-2" | 37'-11" | 30'-9" | 28'-6" | 26'-6" | 24'-7" |
| 2 X 10 X 0.092 X 0.374 SMB | 48'-5" | 45'-7" | 43'-0" | 42'-3" | 38'-8" | 36'-9" | 35'-0" |

| Table Span Note: where tabular span exceeds 40'-0", use 40'-0" |

3.4 Connection Details

The most relevant section of the screened enclosure chapter to the research is the connection details. Connection details are offered in the AAF guide for the entire scope of the aluminum structure. Details of note include column to foundation, screen eave to longitudinal and side walls, purlin to beam, and gutter to host connections. Each detail involves specifications generally for sheet metal screw size and angle size. The sheet metal screw and angles sizes serve
as reliable references and act as a reliable starting point once parametric research is developed. Multiple options of connections add versatility of the AAF guide. For instance, the gutter to host connection is detailed using five separate representations based on common fascia configurations.

3.5 Bracing Strategies

Another important aspect of the screened enclosure chapter is the bracing strategies. The bracing layouts for the structure follow schematics provided by the AAF guide and are influenced by the location of the host structure. Following the layout schematics are the connections details for brace member. Much like the member connections discussed above, the bracing connections suggest size and placement for commonly used hardware. Elevation details for K-type bracing depicts the connection of bracing members to eave rails, girts, and concrete foundations. In addition to K-type bracing details, the AAF guide offers cable bracing details with specified cable diameters and hardware sizes. Bracing strategies do not fall within the scope of this research but certainly play a vital role in the structural health of a screened enclosure.
CHAPTER 4

4. PLAN AND SETUP FOR COMPONENT TESTING

4.1 Specimen Specifications

Connection hardware components were tested in hopes of indentifying the most crucial components which contribute to the overall connection strength. The limitations of the testing apparatus and loading methods mainly determined the specimen dimensions. In order to achieve the best representation of an authentic screened enclosure connection 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 of each beam member was scaled considerably 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 and due to the short length of the specimen.

All specimens were comprised of a 3 ft long gutter with a 2x8 beam member connected perpendicularly. Also, 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. Figure 5 and Figure 6 depict the general configuration of each specimen. The gutter and beam sizes remained constant throughout the specimen design process but the connection components varied substantially. Refer to Figure 5, Figure 6, and Appendix 0 for detailed representations of all 20 specimen types.

The components primarily under investigation included angle size, angle placement, screw size, screw layout, and lag screw presence. The angle sizes ranged from 4x4, 3x3, and 2x2 with some instances of two separate staggered 2x2 angles. Screw sizes differed due to the impact of the screw’s pullout capacity. Standard #14, #8, and #6 sheet metal screws which are commonly used in screened enclosure construction were employed in each connection. In addition to screw size, the screw layout was investigated. The amount of screws on a connection was explored to see whether more screws generated greater comprehensive connection strength.
Each specimen was modeled using a combination of components which served as a comparison tool. In order to differentiate between specimens a particular component would change in size or placement while the complementary components would remain constant. This provided an opportunity to isolate the components and compare their effects on the overall connection capacity. Reference Table 3 for a complete listing of specimen components.
### Table 3: Specimen components

<table>
<thead>
<tr>
<th>Specimen Type</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>
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<td>2x2</td>
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<td>#14</td>
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<td>(2) 1</td>
<td>No</td>
</tr>
<tr>
<td>16</td>
<td>(2) 2x2x2</td>
<td>1/8</td>
<td>Yes</td>
<td>#4</td>
<td>(2) 1</td>
<td>No</td>
</tr>
<tr>
<td>17</td>
<td>(2) 2x2x2</td>
<td>1/8</td>
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<td>#8</td>
<td>(2) 1</td>
<td>No</td>
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<tr>
<td>18</td>
<td>(2) 2x2x2</td>
<td>1/4</td>
<td>Yes</td>
<td>#14</td>
<td>(2) 2</td>
<td>Yes</td>
</tr>
<tr>
<td>19</td>
<td>3x3</td>
<td>1/4</td>
<td>Yes</td>
<td>#14</td>
<td>4</td>
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</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>

### 4.2 Analysis Parameters and Methodology

The performance of each specimen was evaluated using basic comparative elements such as deflection, ultimate force, and yield moment. In order to effectively compare the deflection of each specimen an arbitrary point is selected on the primary structural member of the connection. In this study, the structural member is the protruding 2x8 beam with deflection readings taken at one inch from its far end as shown in Figure 7 and Figure 8.
The load was applied at the end of the extruding 2x8 structural member. More precisely, the load was centered one inch from the specimen edges to promote full surface contact between the loading mechanism and the structural member. This placement provides a flush plane to deliver the load and also prevents slippage and uneven load distribution.

As for the loading, most specimens underwent “yield” type loading, whereas some specimens underwent “fatigue” type loading. Yield loading consisted of increasing the applied force over a series of test runs. Once a specimen test was initiated a force was applied up to a certain value, at which point the deflection was recorded. This sequence took place several times during a specimen test resulting in multiple load versus deflection data points. These data points indicate
how much force is being applied and the corresponding deflection at that applied force. The Fatigue loading followed procedure B of ASTM E-330 (ASTM 2010) 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 to achieve multiple data points.

The multiple data points gathered from the yield and fatigue tests were translated into a load versus displacement graph. The x-axis represents the deflection of the reference point on the specimen and the y-axis represents the load applied. After the load versus displacement graph is developed the curve was analyzed to determine to approximate plastic range of the connection. A yielding strength was assigned to each connection configuration based on the data presented in the load versus displacement graphs. In addition, displacements occurring at the 120 lb mark were used as a starting point in comparing capacities.

When testing specimens, the force was applied until substantial deformation (usually 5 to 7 inches) was obtained. Although the structural member was not completely separated from the gutter due to the ductile nature of the aluminum, plastic failure of the angle and screw pullout were observed at the end of each test. Therefore, it would be reasonable to state that the specimen was loaded to “failure” in each test. These failure mechanisms allow for progressive failure where the structural member is detached during a windstorm.

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(ICC 2007) is intended, so that the behavior of the connections at failure can be investigated.

4.3 Test Setup

A screened enclosure undergoes a variety of fluctuating wind induced loads during a hurricane or strong windstorm. During specimen testing two types of forces were applied to exemplify uplift and windward forces created by wind. Due to the limitations of the testing machine the uplift and windward forces were applied on separate instances. Independent connection capacities were determined for both uplift and windward situations.

A hydraulic MTS machine was used to deliver the uplift and 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.
Case 1 and Case 2 reference the application of windward and uplift forces respectively. The specimens for Case 1 arrangement were positioned with the gutter directed vertically and the beam extruding horizontally through the confines of the MTS machine. In the manner, the MTS machine can deliver a vertical force that simulates a windward force during a hurricane. The specimen arrangement for Case 1 is shown in Figure 9.

![Figure 9: Specimen setup within testing apparatus](image)

As shown in the diagram, 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. For Case 2, In order to simulate a host connection the specimen was fixated to a backdrop to eliminate support underneath the gutter. Without support or fixation the gutter was allowed to bend due to moment about the x-axis. The specimen arrangement for Case 2 is shown in Figure 10.
Both cases have 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 proper data was accomplished using an analysis program called Labview 8.5.1. The Labview 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.
5. EXPERIMENTAL RESULTS OF COMPONENT TESTING

5.1 Failure Definition

After reviewing the load versus displacement graphs of Case 1 loading, 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 in Chapter 6, 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.

5.2 Failure Mechanism

When load was applied to each specimen the failure mechanism showed similar patterns. During the beginning portion of Case 1 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. Refer to Appendix 0 for connection behavior photos.

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.
5.3 Data Interpretation

Case 2 loading failed to offer noteworthy results due to the excessive loads needed to fail the connection. Moreover, the design wind pressures for uplift are substantially lower than pressures in the windward direction. The open nature of the enclosure allows positive uplift pressures to dissipate much easier than windward pressures. Therefore, uplift results proved to be inconsequential compared to the results of Case 1 loading. Accordingly, the following discussions will focus on the behavior under Case 1 loading. The graphs found in Appendix 1.1 provide a good indication of connection performance but does not necessarily demonstrate connection capacity. The basic comparison between specimens takes place between the deflections at a given load and the yield moments. 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 but yield at approximately the same deflection. Although a minor effect, the pre-loading generally increases the deflection at 120 lbs by a ½” to 1” range.

Under Case 1 loading, certain specimens separated themselves with regards to higher connection performance. 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” for Test #1 and Test #2, with the exception of specimen 8. Also, four specimens with an angle thickness of ¼” 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 generally would not be a practical option in 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 ¼” thick angle would expectedly produce the most favorable results. Error! Reference source not found. displays an approximate ranking of specimen connection performance along with the noteworthy components.
Table 4: 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) 2x2</td>
<td></td>
<td>1/4” 1/8”</td>
<td>#14 #8 or #6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>7</td>
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<td>•</td>
<td>•</td>
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<td></td>
<td></td>
</tr>
<tr>
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<td>18</td>
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<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* If unmarked, the specimen uses a type not included in the table. Refer to Appendix 0

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.

In an attempt to evaluate the behavior of each specimen during the full range of loading an additional comparison must be made for loads outside the yielding range. Below are figures describing specimen deflections at 190, 160, 130, 100, and 90 pounds. The absence of data for some specimens indicates that particular specimen failed to reach the specified force before either yielding completely or failing all together. Therefore, the specimens without data indicate the poorest performance. This data representation further proves specimen 7, 13, 14, 18, and 19 perform well under higher pressures. Specimens 8, 11, 15, and 16 failed to hold up even for 100 lbs which indicates poor overall performance. Overall, the deflection values for each specimen
consistently lowered as the load increased. The distribution of specimen deflection offers a look at the load and corresponding deflection of each specimen. When specimens are subjected to smaller loads their deflection values are relatively similar. However, higher loads initiate the disparity between deflections. This proves the components of the better performing specimens operate more efficiently, taking more load but resisting deflection when subjected to higher loads.

Figure 11: Distribution of specimen deflection at 190 lbs of applied load
Figure 12: Distribution of specimen deflection at 160 lbs of applied load

Figure 13: Distribution of specimen deflection at 130 lbs of applied load
Figure 14: Distribution of specimen deflection at 100 lbs of applied load

Figure 15: Distribution of specimen deflection at 90 lbs of applied load
Yield moments of each specimen provided an opportunity for additional performance comparison but more importantly served as the failure criteria needed for the formulation of fragility curves in Chapter 6. The yield moment for each specimen was an average of the yield moments obtained by respective tests. Table 5 displays the average yield moment for each specimen as well as the standard deviation and covariance.

Table 5: Averaged specimen yield moments and parameters

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Averaged Yield Moment (m)</th>
<th>Std dev (σ)</th>
<th>Xi (σ/m)</th>
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<tr>
<td>1</td>
<td>312.50</td>
<td>25.00</td>
<td>0.0800</td>
</tr>
<tr>
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<td>205.83</td>
<td>11.55</td>
<td>0.0561</td>
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<td>300.00</td>
<td>12.50</td>
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</tr>
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<td>395.83</td>
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<td>0.0182</td>
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<td>143.33</td>
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<td>241.67</td>
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<td>314.17</td>
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</tr>
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<td>145.00</td>
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<td>205.83</td>
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<td>20</td>
<td>218.33</td>
<td>6.29</td>
<td>0.0288</td>
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</tbody>
</table>
CHAPTER 6

6. FRAGILITY CURVES

6.1 Full Scale Application

The results presented in Chapter 5, more specifically Table 5, are the product of laboratory testing without the use of realistic wind pressures. In order to compensate for this deficiency, an attempt to convert component results to results in terms of wind speed is necessary. Furthermore, the fragility curve format calls for results in terms of wind speed and also a full scale comparison to determine the probability of full scale enclosure failure.

A full scale enclosure was modeled to exemplify a typical screen enclosure with dimensions based on AAF design tables. The model enclosure has dimensions of 24’ in the traverse direction and 42’ in the longitudinal direction with 6’ intermediate spans. The model enclosure is shown in Figure 16.

![Figure 16: Model full scale enclosure](image)

A mansard roof style stood out as the most practical and typical selection. Since enclosures across Florida contain such a vast amount of different bracing styles, it was decided an unbraced
condition would be used. An unbraced condition compensates for possible poor bracing construction practices. Pin connections were assigned to each column to foundation connection. Regarding the host connection, a spring which allows rotation about the global y-axis was used to to model the connections tested in the laboratory. All other rotations and displacements were fixed leaving moment about the global y-axis as the primary variable, similar to the component specimens. Fixing rotations and displacement about the global x and z axes removes any complexity to the connection and allows a general comparison to be made between full scale connections and the component specimens. To determine the moments resisted by the host connections on the full scale model wind pressures displayed in

Table 1 were applied to the model. Using the finite element program RISA-3D, wind pressures for corresponding wind speeds were applied to allocate induced moments to wind speeds. Determining the stiffness of each connection to assign to full scale model host connections was achieved by calibrating a single member model resembling the component specimens. Using load versus displacement graphs, load increments were applied to the model to achieve the matching deflection shown on the graphs. The range of stiffness found was 4 kip-ft for weaker connections to 10 kip-ft for stronger connections. Overall, the model represents a simplified general example of a full scale screened enclosure.

Three comparative analyses were developed to encompass the variation of connection modeling and account for the individual stiffness of each connection:

1. A group analysis where specimens of similar characteristics are compared to increase the sample size of tests. Larger sample sizes help refine fragility curves. This analysis yields broader and objective results but more accurate probability of failures. The stiffness of 6 kip-ft is used for all groups.

2. Individual specimen analysis comparing each specimen to one another. Substantially smaller sample size yields results more emblematic of a single connection but the probability of failures are drastic, meaning steep fragility curves that show 0% failure probability then 100% failure probability with very little increase in wind speed. This steep increase in failure probability is due to the small sample size. The stiffness of 6 kip-ft is used for all specimens.
3. Individual specimen analysis using the calibrated stiffness for each specimen, opposed to the constant stiffness used in #1 and 2 above. The stronger connections resist higher moments due to higher ($\approx 8$-10 kip-ft) stiffness, therefore, the probability of the stronger connections reaching their respective yield moments is greater than weaker connections.

Results for analysis #1 listed above proved to be more conducive to this research and are presented in Section 6.3. Analysis #2 is excluded from this report because of the small sample size for each specimen. Analysis #3 is also omitted from this report because it requires extensive investigation combined with various bracing options, in order to prevent concentration of the moment on the stiff connection. It should be noted since a constant stiffness is used for analysis #1 the results are generalized. Analysis #1 is designed to group together hardware components based on strength influence and determine the group’s probability of reaching an average yield moment. Considering the variety of possible connection configurations available to contractors, the group approach taken in Analysis #1 may be more practical – even if a connection is not included in the tested 20 types of specimens, we still can refer to a group that is similar to the connection.

6.2 Format of Fragility Curve

As discussed in Section 6.1, specimens were assigned to groups based on comparable hardware components and performance. High performing, moderate performing, and low performing specimens were designated for Group #1, Group #2, and Group #3 respectively. The following table shows which specimens belong to one of three groups.

<table>
<thead>
<tr>
<th>Specimen group assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group #1</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>13</td>
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<tr>
<td>14</td>
</tr>
<tr>
<td>18</td>
</tr>
<tr>
<td>19</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. Lastly, 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, new representative yield moments were determined by averaging all tests within the particular group.

Each group has two types of loading explained in Section 4.2. “Yield” type loading is designated as “A” and “fatigue” type loading is designated as “B”. The yield moments in Table 7 become the main comparable values to the induced moments established during full scale model analysis.

### Table 7: Representative group yield moments and parameters

<table>
<thead>
<tr>
<th>Group</th>
<th>Averaged Yield Moment (m)</th>
<th>Std dev (σ)</th>
<th>Xi (σ/m)</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
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<td>1A</td>
<td>363.81</td>
<td>61.04</td>
<td>0.1678</td>
<td>21</td>
</tr>
<tr>
<td>2A</td>
<td>232.38</td>
<td>70.05</td>
<td>0.3014</td>
<td>21</td>
</tr>
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<td>160.28</td>
<td>36.86</td>
<td>0.2300</td>
<td>18</td>
</tr>
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<td>1B</td>
<td>312.88</td>
<td>52.49</td>
<td>0.1678</td>
<td>14</td>
</tr>
<tr>
<td>2B</td>
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<td>14</td>
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<td>3A</td>
<td>137.84</td>
<td>31.70</td>
<td>0.2300</td>
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</tbody>
</table>

### 6.3 Fragility Results

Fragility results presented in this section describe the probability of failure for the established groups of specimens. Using average group yield moment as the primary failure definition, the probability of meeting or exceeding the yield moment is determined using fragility curve analysis described in Section 2.2. To recap, the probability of failure is defined as:

\[
F_R(V) = \frac{1}{\Xi(m)}
\]

The first parameter investigated is \(F_R(V)\). Utilizing parameters shown in Table 7, \(F_R(V)\) is determined by the following equation [1]:

---

**Equation 3: Fragility of the structure represented by a fragility curve**
where $x = \text{range of moments from 0-465 lbs-ft}$, $m = \text{average yield moment in Table 7}$, $\xi = \text{covariance (} \sigma/m \text{)}$, and $\Phi[\bullet] = \text{standard normal probability integral}$. Figure 17 displays the fragility curve results.

**Figure 17:** $F_R(V)$ fragility curve in terms of applied moment

**Figure 18:** $F_R(V)$ fragility curve in terms of wind speed
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 16. 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 18 and Figure 19 must not be used.

The second parameter needed for fragility analysis is $P_v(V)$, the Weibull PDF for wind speed. Figure 4 shown in Section 2.3 provides the values for $P_v(V)$ within a range of 0-200 MPH. To complete the $P_f$ equation $dV = 10$ MPH, $F_R(V)$ and $P_v(V)$ is integrated from 0-200 MPH yielding the following results:

- Group #1A – $P_f = 0.00269$
- Group #2A – $P_f = 0.03861$
- Group #3A – $P_f = 0.12255$

For pre-loading fragility analysis the group $P_f$ results are:

- Group #1B – $P_f = 0.00585$
- Group #2B – $P_f = 0.06114$
- Group #3B – $P_f = 0.17386$
7. FINANCIAL ANALYSIS

7.1 Format of Financial Analysis

Insurability issues are a common problem regarding homes located in hurricane zones. The combination of hurricane frequency and susceptible screened pool enclosures lead 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 pool 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 Chapter 6. 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.

7.2 Life Cycle Results

According to surveys of local companies specializing in pool enclosure construction the value of aluminum screened pool enclosures is approximately $10,000. This value is representative of an enclosure with the dimensions of the model referenced in Chapter 6. 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:

\[
\text{Equation 4: AAL of failed enclosures}
\]

The variable \( P_f \) (expected annual probability of failure) is formulated using the fragility curves referenced in Chapter 6. Hence, the average annual loss (AAL) for the Group 1 is $10,000 \times 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.

\[
\text{Benefit (B) = AAL - AAL}_{\text{engineered}}
\]

\[
\text{Equation 5: Annual benefit of engineered (retrofitted) connections}
\]

The columns in Table 8 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 $1200 in annual benefit while Group 2 yields $840 when compared to Group 3.

\[
\text{Table 8: Annual benefit of a connection group versus remaining groups}
\]
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:

**Equation 6: Present Value and annual benefit**

where $i$ = real discount rate, due to the use of real dollars in the equation, $n = 1, 10$ years, $B =$ benefit from Table 8, 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 9: Present Value of connection group versus remaining groups**

<table>
<thead>
<tr>
<th>Group</th>
<th>Present Value n = 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3,064.05</td>
</tr>
<tr>
<td></td>
<td>10,224.30</td>
</tr>
<tr>
<td>2</td>
<td>-3,064.05</td>
</tr>
<tr>
<td></td>
<td>7,160.25</td>
</tr>
<tr>
<td>3</td>
<td>-10,224.30</td>
</tr>
<tr>
<td></td>
<td>-7,160.25</td>
</tr>
</tbody>
</table>

Essentially, when $n = 1$ the Present Value is the same as the annual benefit but Table 9 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 9, 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. If the present value for Group 1 connections in a single year is compared with accompanying initial costs only then would there be detrimental results assuming the connections fails within one year of enclosure construction.

7.3 Overall Impact of Financial Analysis

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.
CHAPTER 8

8. CONCLUSIONS

8.1 Scope and Objective

The scope of this research involved testing the performance of connections modeled to resemble those on an aluminum screened pool enclosure. More specifically, the host connection was investigated by constructing 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.

8.2 Methodology

Preliminary 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 of the connections was examined using fragility curves. In order for the concept of fragility curves in terms of wind speed to be validated, the data found through laboratory testing was translated using a full scale structure modeled using the RISA-3D analysis program. Design wind pressures were applied to the model structure simulating induced moments found at the host connection. The wind induced moments were then compared to the specimen yield moments found through testing. This comparison lead to a fragility curve describing the failure probability of a connection at a given wind speed.
After probability of connection failure was established, it remained to be seen what would be the financial impact. A financial model comparing the benefit of one group of connections over another was developed using life cycle cost analysis. Overall, finding the financial benefit of one connection compared to another helped further differentiate between high or low performing specimens.

8.3 Testing Results

Testing results presented in Chapter 6 show distinct differences between connection types. Preliminary testing concluded that specimens consisting of a combination of (2) staggered 2x2 angles, 1/4” thick angles, 3x3 angles, and/or a screen attachment yielded the best results. Of course, thicker hardware is usually assumed to generate better performance however current construction practices do not necessarily utilize more hardware due to material complications with manufacturers or lack of financial benefit provided. These results aim to assign positive financial benefit to using better performing hardware.

The fragility results determined probability of failure for three separate groups of specimens. Expectedly, the better performing group of connections failed at much higher wind speeds than the other groups of moderate to poor performing specimens. Group #1 saw probability of failure beginning at 140 MPH wind speeds while Group #2 and #3 began showing signs of failure around 50-80 MPH wind speeds. Accounting for wind speed probability using South Florida conditions, the annual probability of connection failure for each group was:

- Group #1 – \( P_f = 0.00269 \)
- Group #2 – \( P_f = 0.03861 \)
- Group #3 – \( P_f = 0.12255 \)

The financial benefit seen from using Group #1 specimen types was almost $400 in reduced losses compared to Group #2 and $1200 compared to Group #3. In extreme cases where connection failures are experienced on a yearly basis for 10 years, the Group #1 financial benefit increases to $3000 compared to Group #2 and $10,200 compared to Group #3.

In summary, keeping analytical assumptions in mind, this research produced notable conclusions:
1. 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.

2. Reductions in connection failure lead to decreased financial losses. This relieves both the home owner and insurance companies of considerable costs repairing and replacing screened enclosures.

3. Connections implementing weak hardware, whether for financial or aesthetic purposes, have high failure rates. New configurations involving weak hardware or upgraded hardware should be considered.

**8.4 Future Research**

Primarily, this research should be viewed as a general proposal to the aluminum enclosure industry. Widespread construction practices make this research isolated to only a select group of connection types and analytical procedures. Due to the limitations of the testing machine, connections were only subjected to laboratory conditions differing from the field conditions present during a hurricane or strong wind storm.

Research pertaining to screened enclosure host connections is practically non-existent 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. A representative stiffness was used for the full scale model analysis however it was found that each connection possesses a distinct stiffness. This led to higher performing specimens accepting more load and thus failing more often according to fragility analysis. The redistribution of loads over a full scale structure should be explored in order to explain this issue.
APPENDIX A

Specimen Details

Figure 20: Specimen 2 Side View

Figure 21: Specimen 2 Front View
Figure 22: Specimen 3 Side View

Figure 23: Specimen 3 Front View
Figure 24: Specimen 4 Side View

Figure 25: Specimen 4 Front View
Figure 26: Specimen 5 Side View

Figure 27: Specimen 5 Front View
Figure 28: Specimen 6 Side View

Figure 29: Specimen 6 Front View
Figure 30: Specimen 7 Side View

Figure 31: Specimen 7 Front View
Figure 32: Specimen 8 Side View

Figure 33: Specimen 8 Front View
Figure 34: Specimen 9 Side View

Figure 35: Specimen 9 Front View
Figure 36: Specimen 10 Side View

Figure 37: Specimen 10 Front View
Figure 38: Specimen 11 Side View

Figure 39: Specimen 11 Front View
Figure 40: Specimen 12 Side View

Figure 41: Specimen 12 Front View
Figure 42: Specimen 13 Side View

12" deep wood blocking insert to prevent local failure
2x8 Aluminum Beam
4/12 Slope
3 x 3 x ½ Angle each side of beam
2x8 Roof Eave

8" dia. Lag screw each side of beam thru angle
6" or 7" Super Gutter

1-0"
2'-7"
(4) #14 S.M.S each side of beam

Figure 43: Specimen 13 Front View

12" deep wood blocking insert to prevent local failure
2x8 Aluminum Beam

6" or 7" Super Gutter
3 x 3 x ½ Angle each side of beam
2x8 Roof Eave

8"
3'-0"
(2) #14 S.M.S each side of beam
(4) #14 S.M.S each side of beam

8" dia. Lag screw each side of beam thru angle
Figure 44: Specimen 14 Side View

Figure 45: Specimen 14 Front View
Figure 46: Specimen 15 Side View

Figure 47: Specimen 15 Front View
Figure 48: Specimen 16 Side View

Figure 49: Specimen 16 Front View
Figure 50: Specimen 17 Side View

Figure 51: Specimen 17 Front View
Figure 52: Specimen 18 Side View

Figure 53: Figure 18 Front View
Figure 54: Specimen 19 Side View

Figure 55: Specimen 19 Front View
Figure 56: Specimen 20 Side View

Figure 57: Specimen 20 Front View
APPENDIX B

Load-Displacement Curves (Case 1)

Figure 58: LvD Specimen 1 Test 1

Figure 59: LvD Specimen 1 Test 2
Figure 60: LvD Specimen 1 Test 3
Figure 67: LvD Specimen 4 Test 1

Figure 68: LvD Specimen 4 Test 2

Figure 69: LvD Specimen 4 Test 3
Figure 70: LvD Specimen 5 Test 1

Figure 71: LvD Specimen 5 Test 2

Figure 72: LvD Specimen 5 Test 3
Figure 73: LvD Specimen 6 Test 1

Figure 74: LvD Specimen 6 Test 2

Figure 75: LvD Specimen 6 Test 3
Figure 82: LvD Specimen 9 Test 1

Figure 83: LvD Specimen 9 Test 2

Figure 84: LvD Specimen 9 Test 3
Figure 85: LvD Specimen 10 Test 1

Figure 86: LvD Specimen 10 Test 2

Figure 87: LvD Specimen 10 Test 3
Figure 88: LvD Specimen 11 Test 1

Figure 89: LvD Specimen 11 Test 2

Figure 90: LvD Specimen 11 Test 3
Figure 94: LvD Specimen 13 Test 1

Figure 95: LvD Specimen 13 Test 2

Figure 96: LvD Specimen 13 Test 3
Figure 97: LvD Specimen 14 Test 1

Figure 98: LvD Specimen 14 Test 2

Figure 99: LvD Specimen 14 Test 3
Figure 112: LvD Specimen 19 Test 1

Figure 113: LvD Specimen 19 Test 2

Figure 114: LvD Specimen 19 Test 3
Figure 115: LvD Specimen 20 Test 1

Figure 116: LvD Specimen 20 Test 2

Figure 117: LvD Specimen 20 Test 3
APPENDIX C

Component Testing Photos (Selected Specimens)

Figure 118: Specimen 1 Photo

Figure 119: Specimen 1 Photo
Figure 120: Specimen 6 Photo

Figure 121: Specimen 6 Photo
REFERENCES


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BIOGRAPHICAL SKETCH

Michael Schellhammer was born on June 24, 1986 in Lansing, MI. He attended Florida State University from 2004 to 2008 where he earned a Bachelor of Science degree and Cum Laude distinction in Civil Engineering. After completing his undergraduate studies, Michael continued his education by enrolling in the Structural Engineering Masters program at Florida State University. Since 2009 Michael has worked extensively on wind related topics with Dr. Sungmoon Jung pertaining to his thesis.