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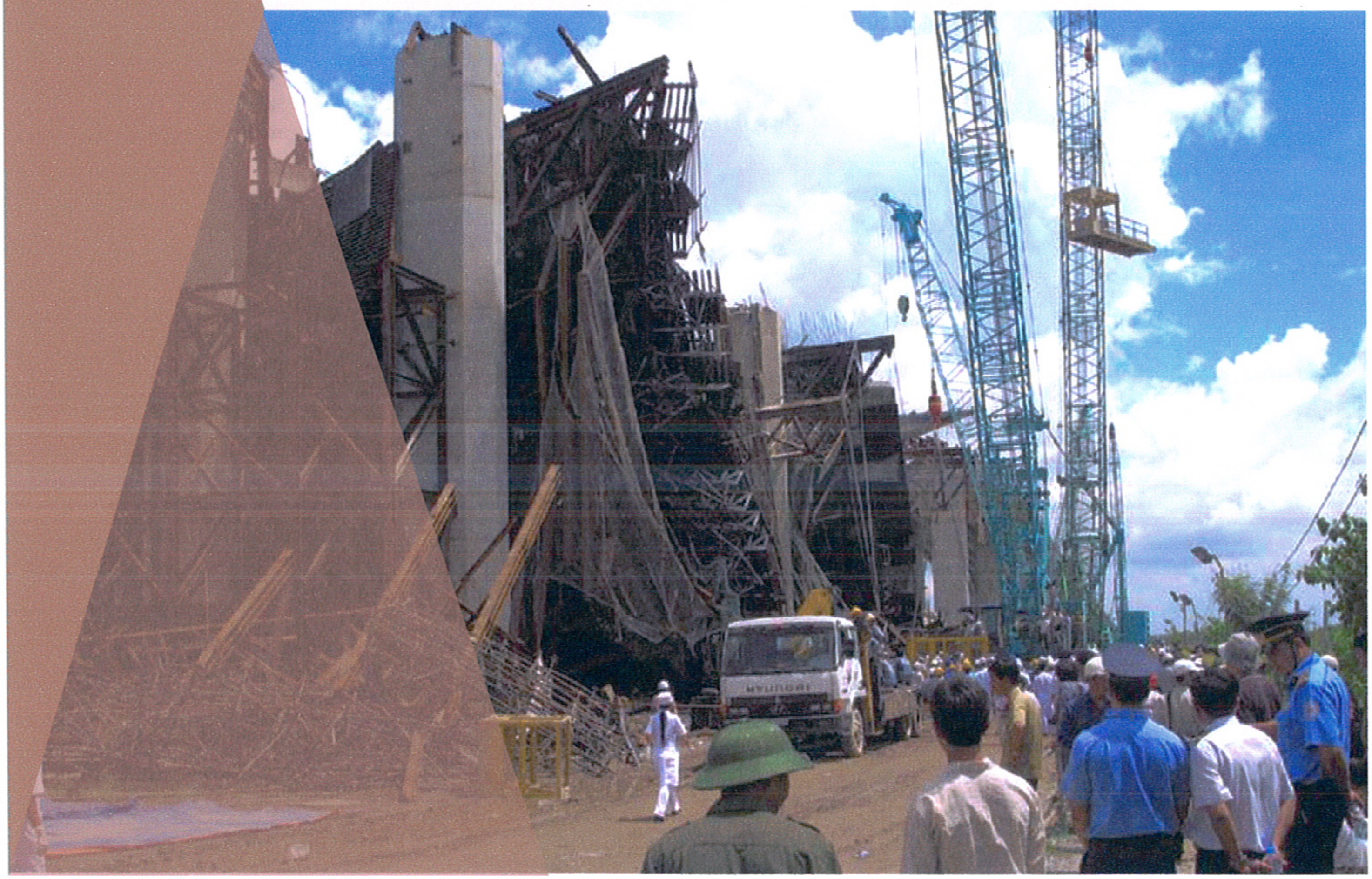

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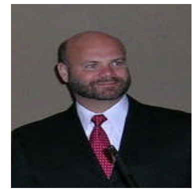

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Structural Performance of Aluminum Frame Screen Enclosures during the 2004 and 2005 Hurricanes in South Florida.

We present an analysis of the changes in the building code from the 1980's to present in the design of aluminum frame screen enclosures in South Florida including the South Florida Building Code, the Standard Building Code, the 2001 Florida Building Code, and the 2004 Florida Building Code. Aluminum frame screen enclosures are typically used to enclose swimming pools and patios at South Florida houses. Although failures of aluminum frame screen enclosures typically do not have a major impact on life safety, the cost of replacement of these structures is often in excess $20,000 USD. Our research includes a review the structural performance and failure of these structures when subjected to wind loading, specifically during the 2004 and 2005 hurricane seasons. We performed finite element analysis of a typical aluminum frame screen enclosure subjected to different wind loads. Our results show that screen enclosures have been under designed in the past given the prescriptive requirements and the assumption that they are rigid structures with a gust factor of 0.85. Based on our analysis screen enclosures are flexible structures with a natural frequency well below 1Hz. Given that the screen enclosure is a flexible structure the gust factor value determined in accordance with ASCE 7 is approximately 1.5 for a wind speed of 140mph and 5% damping. Our results indicate that the prescriptive code requirements should be reconsidered. We also recommend that design procedures include the evaluation of gust response considering screen enclosures to be flexible structures.

Structural performance of aluminum frame screen enclosures during the 2004 and 2005 hurricanes in South Florida

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Introduction

The Florida Building Code (FBC) defines a screen enclosure as a building or part thereof, in whole or in part self-supporting, and having walls of insect screening with or without removable vinyl or acrylic wind break panels and a roof of insect screening, plastic, aluminum, or similar lightweight material. See Figure 1 for an example of a typical screen enclosure.

Figure 1 – Typical Screen Enclosure

In the past few years South Florida has been in the news due to the busy 2004 and 2005 hurricane seasons, which included Hurricanes Charlie, Frances, Jeanne, Wilma, and Katrina. Depending on the specific location, buildings and other similar structures are required to be designed to sustain wind speeds of up to 156 mph (3-sec gust) in accordance with the Florida Building Code (FBC) and ASCE 7 (American Society of Civil Engineers). In Miami-Dade and Broward Counties the design wind speeds are 146 mph and 140 mph, respectively. (See Figure 2)

Although failures of aluminum frame screen enclosures typically do not have a major impact on life safety, the cost of replacement of these structures is often in excess $20,000 USD. The replacement of these structures affects the cost of homeowners property insurance premiums and the way these policies are written and adjusted.

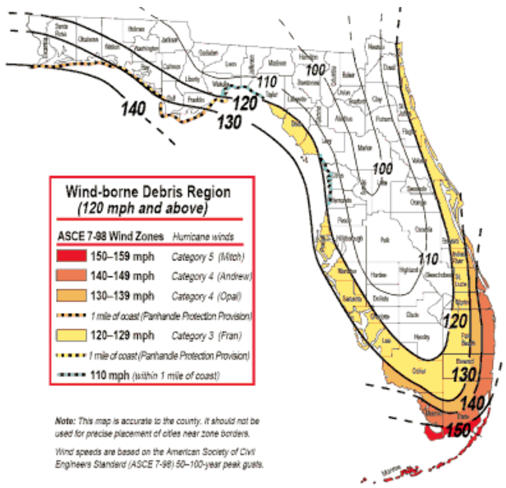

Figure 2 – FBC (ASCE 7) Wind Speed Contour Map

Aluminum screen enclosures behavior during hurricanes

It has been our experience after inspecting hundreds of screen enclosures throughout Florida that the most common damages to screen enclosures as a result of wind forces included missing and or torn screens (See Figure 3), bent or bowed overhead beams (See Figure 3), leaning of screen enclosure walls (See Figure 4), sheared diagonal braces at connections (See Figure 5), failure of diagonal braces (See Figure 6), deformation and or distress at connections (See Figure 7), and shearing at connection bolts (See Figure 8).


Figure 3 – Bent beams

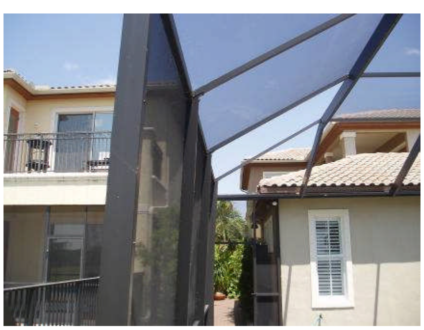
Figure 4 – Leaning of screen walls

Figure 5 – Missing diagonal members and screens

Figure 6 – Failure of diagonal braces

Figure 7 – Distress at connections

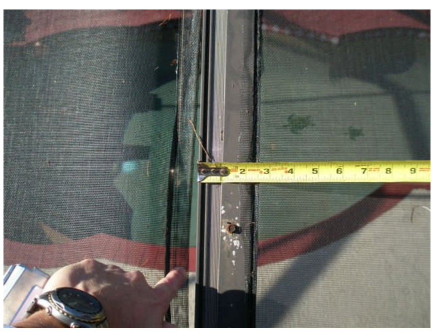

Figure 8 – Shearing of fasteners, torsional stress in overhead beam due to racking of structure

Florida Building Code

Prior to 2002 Florida was governed by two primary building codes; the Standard Building Code (SBC), which was a model building code prevalent throughout much of the southern United States, and the South Florida Building Code (SFBC). The SFBC was applicable only in Miami-Dade and Broward Counties and both counties had their own versions, although they were basically the same. The SBC was generally applicable throughout the rest of the state.

In the late 1990s the Florida Legislature dictated that the entire state would have one building code by a specific date. At about the same time the International Building Code (IBC) was being developed to basically combine the three model building codes throughout the country. However, the IBC was not going to be ready in time to meet the deadline set by the Florida Legislature. As a result Florida adopted its own code, the 2001 Florida Building Code, in March 2001.

The 2001 FBC was essentially a combination of the SBC and the SFBC. The old SFBC had more stringent wind load requirements and South Florida was not willing to compromise the provisions they enacted after Hurricane Andrew in 1992. Correspondingly, much of the rest of the state was not willing to enact the more stringent wind / hurricane provisions in the SFBC. The result was the creation of the High Velocity Hurricane Zone (HVHZ). The HVHZ has little to do with physical reality or probability of hurricanes; it was a political designation and included Miami-Dade and Broward counties only. The old provisions of the SFBC were basically incorporated into the HVHZ provisions, applicable in Miami-Dade and Broward only, while the rest of the state was governed by the main body of the code, which was the old SBC. Essentially the 2001 FBC was two codes in one.

On 1 October 2005, just prior to Hurricane Wilma, the 2004 FBC replaced the 2001 code. The 2004 FBC maintained the HVHZ provisions however the main body of the code was basically replaced with the IBC provisions, and is the code in effect as of the writing of this paper.

Chapter 20 of the 2004 FBC provides the requirements for design and construction of aluminum frame screen enclosures. The main body of Chapter 20 provides a prescriptive table of wind pressures for the design wind pressures for aluminum screen enclosures outside the HVHZ, Table 2002.4. The portion of the chapter in the code applicable to the design of aluminum screen enclosures in the HVHZ requires that screen enclosures be designed in accordance to ASCE 7-02 for wind. ASCE 7 and the FBC provide the load combinations. For wind, the governing combination for screen enclosures is typically 0.6Dead+Wind.

A review of older codes revealed the following: 1994 SFBC specified a 15psf design wind load for typical 20/20 mesh screens. The SBC up to 1999 provided minimal guidance for designing screen enclosures and referred the designer to the Specifications for Aluminum Structures, Aluminum Construction Manual.

Screen enclosure analysis

We analyzed a typical screen enclosure located in Broward County with exposure category C, a design wind speed of 140mph (3-sec gust) assuming simple supports, pinned column to beam connections, with the frame attached to the house roof edge at two sides using the finite element analysis program RISA 3D. The wall height was 9ft; the overall height was 12ft; the frame spacing was 7ft in the east-west direction and 8ft in the north-south direction, with a 20/20 mesh screen. The 20/20 mesh screen is 45% solid. The overhead framing was 2x6 aluminum Self Mating Beams (SMB). A damping ratio of 5% was assumed as a reasonable value for bolted metal frame.

The analytic procedure for wind loading in accordance with ASCE 7-02 was used for the analysis of the screen enclosure. Section 6.5 was used for the design of the wind loads for open signs and lattice frameworks. The design wind speed was varied until there was no overstress in the members. Other factors included I=0.77 (Importance Factor), K_z=0.85 (Exposure Category / Height Factor), K_{zt}=1(Topographical Factor), and K_d=0.85 (directionality factor).

First, a unit load was applied to the structure in each direction independently and the natural frequency of the structure was determined. The natural frequency (f) was found to be approximately 0.4Hz, which means that the structure is flexible as defined by ASCE 7. Given a flexible structure ASCE 7 requires that the gust factor effect (G) be calculated. For rigid structures (f>1.0Hz) a G=0.85 is allowed. It is our experience that designers have typically used G=0.85 for screen enclosures in the past. Using the ASCE 7 method for determining gust response we determined that G=1.5 for a 140mph design wind speed, a damping ratio of 5% and f=0.4Hz. This value is significantly greater than 0.85 that has been used as a default for rigid structures.

The structure was analyzed with the following considerations:

1. Wind blowing north, roof pressure up
2. Wind blowing north, roof pressure down
3. Wind blowing south, roof pressure up
4. Wind blowing south, roof pressure up
5. Wind blowing east, roof pressure up
6. Wind blowing east, roof pressure down
7. Wind blowing west, roof pressure up
8. Wind blowing west, roof pressure down.

The following is a summary of our analysis using a design wind speed of 140mph:

1. Gust Response Factor (G) $= 0.925((1 + 1.71I_ž(g^2_QQ^2 + g^2_RR^2)^{1/2}) / (1 + 1.7g_vI_ž)) = 1.5$
2. Velocity Pressure $q_z = 0.00256K_zK_{zt}K_dV^2I = 27.9$psf
3. Screen Pressure Pscreen=$q_zGC_fA_f$ = 30.3psf with C_f = 1.6, A_f = 0.45 (A_f =Asolid/Agross), G = 1.5. Pscreen takes in to account that a typical screen mesh for screen enclosures has a wire or thread diameter of 0.13in. For a 20/20 mesh screen the density is 45% solid. These values must be adjusted for roof and wall factors according to FBC 1622 with 0.7 and 1.3 respectively.
4. As such, Proof = 21.2psf and Pwalls = 39.5psf.

See Figures 9 through 13 for beam and column loading and envelope solution for V=140mph.

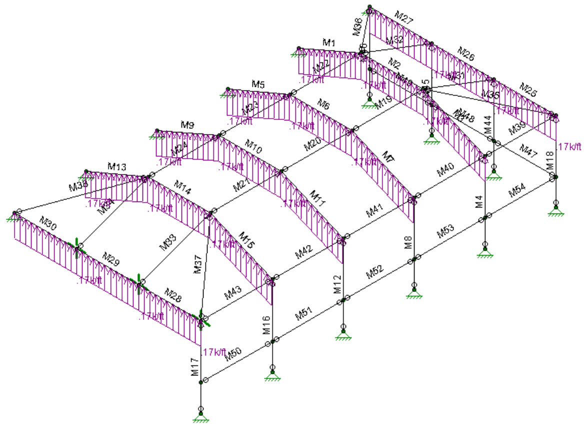

Figure 9 - Beam Load: Spacing (8ft) x Pressure (21.2psf) = 0.17k/ft

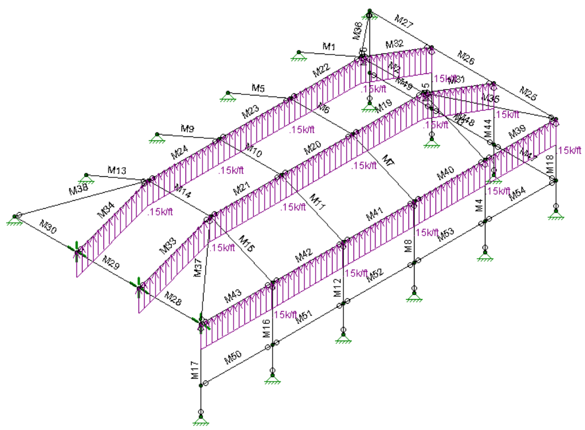

Figure 10 - Beam Load: Spacing (7ft) x Pressure (21.2psf) = 0.15k/ft

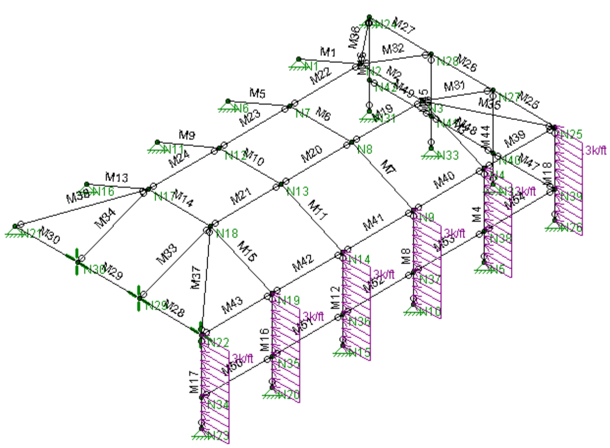

Figure 11 - Post Load: Spacing (8ft) x Pressure (39.5psf) = 0.3k/ft

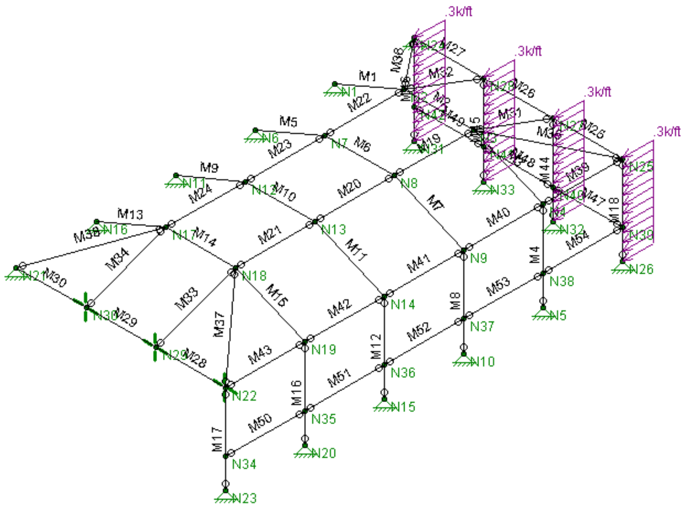

Figure 12 - Post Load: Spacing (7ft) x Pressure (39.5psf) = 0.3k/ft

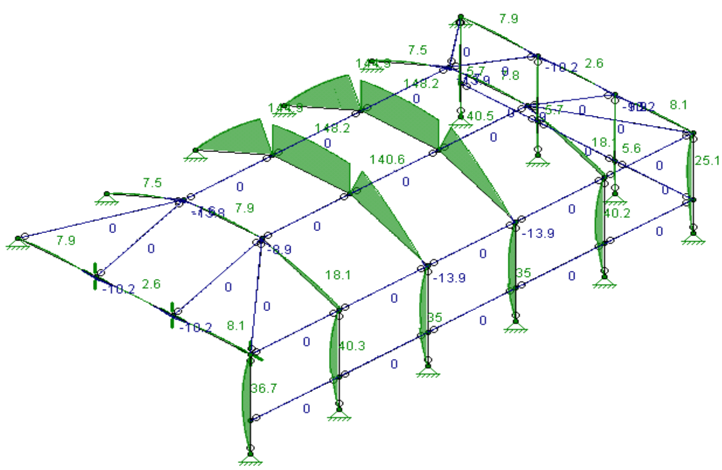

Figure 13 - Envelope Solution – Member Bending Moments (k-in) for 140mph.

As seen in Figure 13, members 6 and 10 have the greatest bending moment of 148.2 k-in and 1.3kp axial load. The area of 2x6 SMB is 1.056in^2. The interaction ratio for a 2x6 SMB:

> Applied /allowable = 148.2k-in/13.2k-in moment + 1.3k/2.8k axial = 11>1
> Therefore, a 2x6 SMB is not sufficient for this loading and is significantly overstressed.

The area of 2x10SMB is 3.198in^2. The interaction ratio for a 2x10 SMB:

> Applied/allowable = 148.2k-in/114.4k-in moment + 1.3k/8.8k axial= 1.45>1.
> Therefore, a 2x10 SMB is not sufficient for this loading and is overstressed.

We similarly analyzed the same screen enclosure for design wind speeds of 130 mph, 125 mph, 110mph, 90 mph, 70 mph, and 50 mph. Our results indicated that 2x10 SMB were not overstressed at 125mph. The 2x6 SMB were overstressed at 70mph but not at 50mph. The 2x6 SMB was significantly overstressed at winds speeds above 110 mph. The 2x6 SMB were overstressed at wind speeds between 90 mph and 70mph but potentially not overstressed to the extent that failure would be expected.

For comparison purposes we used the prescriptive table applicable to non HVHZ. We used the design pressure values highlighted in blue on this table for 140mph in RISA 3D with simultaneous loading. As mentioned before, for non HVHZ, the 2004 FBC has a prescriptive table, Table 2002.4 revised on December 8, 2006, which is used for the design of aluminum screen enclosures with an importance factor of 0.77. This table is not allowed to be used in the HVHZ. See Table 1 below. The following is a summary of our findings:

The interaction ratio for a 2x6 SMB:

> Applied /allowable = 133.7k-in/13.2-in moment + 0.834k/2.8k axial = 10.4>1. Therefore, a 2x6 SMB is significantly overstressed for this loading.

The interaction ratio for a 2x10 SMB:

> Applied /allowable = 133.7k-in/114.4k-in moment + 0.834k/8.8k axial = 1.25>1. Therefore, a 2x10 SMB is also overstressed for this loading.

We similarly analyzed the same screen enclosure for design wind speeds using the prescriptive table for the design pressure values at 120mph. The 2x6 SMB was significantly overstressed for this loading but the 2x10 SMB was adequate and not overstressed for this loading.

Table 1. 2004 FBC Table 2002.4 (post December 8th, 2006)

	Basic Wind Speed (mph)											
	100		110		120		130		140		150	
Surface	Exposure Category (B or C) Design Pressure (psf)											
	B	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**
Horizontal Pressure on Winward Surfaces	12	17	13	18	15	21	18	25	21	29	24	33
Horizontal Pressure on Leeward Surfaces	10	13	10	14	13	17	14	19	15	23	18	27
Vertical Pressure on Screen Surfaces	3	5	4	5	4	6	5	7	6	8	7	9
Vertical Pressure on Solid Surfaces	10	14	11	15	13	18	15	21	17	24	20	28

Comparison of Results

From the table below it is observed that the design pressures when the gust factor is calculated based on a flexible structure are higher in value than the values in Table 2002.4 of the 2004

FBC (revised in December 2008), higher than the values when a gust factor is assumed to be 0.85, and higher than the 1980's and 1990's SFBC. The values of qz, Pscreen, Pwalls, and Proof were calculated for gust factors of 1.5 and 0.85 for a wind speed of 140mph.

Table 2. Comparison of Design Pressures

Design Pressures (psf) for V=140mph, Exposure Category C

	G = 1.5 FBC HVHZ (ASCE 7) (flexible structure)	G = 0.85 FBC HVHZ (ASCE 7) (rigid structure)	2004 FBC Table 2002.4 (NON-HVHZ)	1990s SFBC
Pscreen	30.3	16		15psf
Pwalls	39.5	20.8	23 (leeward) or 29 (windward)	15psf
Proof	21.2	11.2	24 (on solid surfaces) or 8 (on screens) = value closer to 8	15psf

Conclusions

Screen enclosures have been under designed in the past given the prescriptive requirements and the assumption that they are rigid structures therefore limiting their gust factor to 0.85. Based on our RISA 3D analysis, screen enclosures are flexible structures with a natural frequency well below 1Hz. Given that the screen enclosure is a flexible structure the gust factor value determined in accordance with ASCE 7 is approximately 1.5 for a wind speed of 140mph and 5% damping. The greater gust factor increases the design pressures including the wall and roof pressures. The 2x6 SMB overhead beams were significantly overstressed under the current 2004 FBC for 140mph (3-sec gust). The 2x10 SMB overhead beams were overstressed as well under the current 2004 FBC for 140 mph but were satisfactory for 125mph.

During Hurricanes Wilma and Katrina wind gusts were in the order of 80mph to 120mph. The damages found during our inspections to screen enclosures fabricated with 2x6 SMB correlate to the findings in our analysis given the overstress in the members. Based on our results it appeared that the prescriptive values in Table 2002.4 of the FBC should be reconsidered. We also recommend that design procedures include the evaluation of gust response considering screen enclosures to be flexible structures. Further study is needed to better understand the gust response for aluminum frame screen enclosures.

Notations/Abbreviations

A_f = Asolid/Agross
ASCE = American Society of Civil Engineers
C_f = force coefficient
f = natural frequency
FBC = Florida Building Code
G = gust response factor
g_Q = peak factor for background response
g_R = peak factor for resonant response
g_v = peak factor for wind response
HVHZ = High Velocity Hurricane Zone

I =Importance Factor
$I_{\bar{z}}$ = intensity of turbulence
IBC = International Building Code
K_z=Exposure Category / Height Factor
K_{zt}= Topographical Factor
K_d= directionality factor
Q = background response factor
q_z = velocity pressure
R = resonant response factor
SBC = Standard Building Code
SMB = Self Mating Beams
SFBC = South Florida Building Code
V = wind speed

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