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Nineteenth Australasian Wind Engineering Society Workshop, April 4-6, 2018, Torquay, Victoria

Cyclone Resistant Glazing in Florida, USA – Saving Homes & Businesses

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ABSTRACT

When Hurricane Andrew hit South Florida, USA in 1992, the need for urgent building code revisions became apparent. Urged on by the insurance industry, the South Florida Building Code was revised in 1994 to include test provisions for glazing systems to withstand hurricane wind pressures and impacts from wind-borne debris. These were based on Technical Report 440 (1977) from Australia and involve impact from a 4.1-kg timber missile at 15.25 m/s and cyclic pressure loading after impact. ASTM and ISO standards followed. These code and test standard revisions, combined with a strict product approval system for building envelope components, have proven to be highly effective. This paper details the hurricane impact building codes and test standards adopted in the USA. Case studies are provided on the effectiveness of code compliant hurricane impact glazing systems in Hurricane Wilma (2005) and most recently in 2017 Hurricane Harvey and Hurricane Irma.

1. Introduction

Despite evidence that tropical cyclones, called hurricanes in the USA, can cause widespread damage due to impact from wind-borne debris, there were no codes in place in the USA until 1994 to ensure that the design of the glazing system was capable to withstand the high wind forces and debris generated. This all changed when Hurricane Andrew in 1992 hit Homestead Florida 64 km south of Miami.

2. Hurricane Andrew and the birth of hurricane codes in the USA

Insurance claims from Hurricane Andrew totaled an amount equivalent to $25 billion today. The insurance companies were not prepared to handle the high cost of claims, and as a result there was strong support for a strengthening and enforcement of building code requirements. Analysis of the damage sustained by Hurricane Andrew exposed a clear need to have improvements in building glazing systems. Failures occurred as a result of both the wind-borne debris damaging the glass, as well as the strong winds themselves ripping the whole window system off of the building. The openings created in buildings caused water to penetrate as well as internal pressure leading to building collapse. It was quite evident that improvements in the glazing system design could have helped mitigate the damage. Miami-Dade County developed the first hurricane code. It required testing and product approval of the entire fenestration system. If the glass remains, intact but the frame fails, the building envelope will be open to water and wind damage. The system approach was adopted so that all components are evaluated during testing. The Miami-Dade County of Florida implemented codes in September 1994 based on the TR 440 Report (1977) from Australia. The testing required was as follows:

1. Large Missile Impact Resistance for the first 9.1 metres from the finished grade - 4.1 kg timber missile impact at 15.25 m/s. A pass-fail criterion was set to minimize water intrusion and unauthorized entry after the event.

2. Small Missile Impact Resistance - debris protection from 9.1 metres to 20 metres above finished grade. The spherical steel 2-gram debris missile used was based on an existing ASTM standard for roof gravel.
3. Pressure Cycling - The pressure cycling designed to replicate the advance and departure of a hurricane.

It was clear that Florida needed a statewide code and in 1996, the Florida Building Commission was created to develop codes. In 2002, the Florida building codes were developed. In addition, the Florida Building Commission established a product approval system for building envelope components. All window and door systems were to be tested and approved for use in the State of Florida. For buildings in Miami or Broward County, the glazing system must be approved by Miami-Dade County and receive a 'Notice of Acceptance'.

3. Development of testing standards

In addition to the Florida testing protocols ASTM standards were developed. ASTM E1886 defines both small and large missile impact testing requirements and the cyclical portion of the testing. In addition, this standard establishes testing conditions regarding allowable test temperatures, load duration during the cyclical testing, as well as other testing parameters. In ASTM E1996 requirements for hurricane impact systems there are two levels, basic protection (Level D) and enhanced protection (Level E). The enhanced protection covers essential facilities such as hospitals, police stations, fire rescue stations, emergency centers, jails and detention centers and buildings critical to the national Defence. For basic protection, 9.1 metres and above in buildings, small missile impact requirements need to be meet. For the first 9.1 metres, depending on the wind zone, the 4.1 kg missile speed is 15.25 m/s for Level D and 24.38 m/s for Level E – refer to Table 1.

Missile Level	Missile Size	Missile Speed
A	2-gram steel ball	39.62 m/s
C	2.05 kg 50 mm x 100mm 1.2 m lumber	12.19 m/s
D	4.1 kg 50 mm x 100mm 2.4 m lumber	15.25 m/s
E	4.1 kg 50 mm x 100mm 2.4 m lumber	24.38 m/s

Table 1. ASTM E1996 Missile Size and Speed

The ASCE-7 Wind Zone maps are used to determine the wind zone and performance level needed for a building depending its location. The wind zone regions were determined based on information about wind speeds for different categories of hurricanes. The Saffir-Simpson hurricane scale is used world-wide to characterize the severity of hurricanes. Today, there are three options allowed in the state of Florida for protecting the glazing system from wind-borne debris from hurricanes:

1. Plywood except in areas where the wind is greater than 225 KPH such as HVHZ
2. Approved shutters
3. Approved impact resistant windows or doors

The use of plywood, or even shutters, is not very practical or attractive particularly in multi-storey buildings. In these cases, the use of impact resistant glazing system is preferred. Quite often, there is loss of power during hurricanes and using an impact glazing system will allow natural lighting to enter the building. Impact glazing systems use laminated glass to provide impact protection as well as a specially designed frame to withstand the wind forces. According to FEMA (Federal Emergency Management Agency), the recommendation is to use impact-glazing systems as they provide protection that does not require any human involvement to install. This is often the costlier option, but may be the most appropriate for vacation homes, high end homes or in upper levels where installation of shutters is both difficult and dangerous.

4. Considerations when designing hurricane impact glazing systems

In order for a glazing system to be effective in mitigating damage form wind-borne debris the whole system needs to be designed properly to resist the storm event. The framing system as well as how the glass is installed in the framing system is just as important as the impact resistance of the glass. When designing glazing system for a building is important to understand what kind of wind loads the building will experience. The type of impact testing required will be determined by the location of the building and the wind zone. The pressure cycling required will be determined by not only the wind zone region but also the shape of the building, height of building, location of the building in relation to other buildings and the size of the window itself. This becomes more important in urban settings were the wind loads can increase based on the surrounding buildings, resulting in a tunneling effect of the wind.

5. Before Florida there was Australia

The very first building code for protection from wind-borne debris in cyclones was put in place in Australia soon after the devastation caused by Cyclone Tracy which hit the city of Darwin on Christmas Eve 1974. The Darwin Building Manual was issued in 1975, and specified that buildings be designed for full internal pressure in event of a cyclone unless approved debris protection of windows and glass in doors was provided. Approved debris protection was defined as the ability to prevent a 4 kg piece of timber missile 100 mm x 50 mm travelling at 20 m/s from causing a dominant opening. Although the Pilkington ACI Company launched “Triplex” 13.8 mm Cyclone Resistant Glass in January 1977, most of the improvements were aimed preventing roof failures under cyclic pressures rather than on the design of cyclone resistant glazing systems. For cyclone prone areas outside of Darwin design guidelines were developed at a workshop, organized by the then Commonwealth Department of Housing and Construction, and published in July 1977 in Technical Report 440. TR 440 recommended an impact speed of 15 m/s for the 4 kg timber missile. This debris impact requirement was adopted in the 1989 revision of the AS 1170.2 Loading Code. Cyclic pressure testing following missile impact was not specified in the Code. In 2011, a change was made to AS/NZS 1179.2 increasing the speed from 15 m/s to 0.4 of the regional velocity (28 m/s in Region C and 35 m/sec in Region D). The basis for this increase was a conclusion from wind studies in the USA that the 4 kg timber missile picked up by a 69 m/s wind gust would accelerate from rest to 15 m/s in less than 2 metres. Previously, it had been concluded (JDH 99/1 report on ‘Debris Damage for Cyclone Shelter Buildings in Queensland’) that the 4 kg missile would have travelled almost a kilometre before reaching a speed of 20 m/sec, and that this “is clearly an extreme event”. The increase in missile speed in AS/NZS 1170.2:2011 has greatly increased the cost of glass and framing that can meet the new requirements. As a result, buildings are being built without the use of impact glazing. Failed windows allow rain, wind and debris to enter causing high amounts of damage to building interiors and belongings, and potentially injury or death to building occupants.

6. Eleven years after the codes in Florida went into effect they were tested

The building codes in Florida were put to the test when in 2005 hurricane Wilma hit south Florida causing $21 billion dollars in damage and killing 21 people. It was of great interest to the Miami-Dade County Building Code Compliance Office to assess damage in the field to determine how effective these codes were in reducing damage to building structures. The findings are summarized in the Post Hurricane Wilma Progress Assessment report. Hurricane Wilma affected many high-rise buildings in the area. Investigation showed that none of the buildings that were built under the new building codes sustained any damage to the glazing system. The buildings that were built before the current codes showed damage to the windows, curtain walls and sliding glass doors. Where the damage occurred, there was interior water damage and rise in internal pressure inside the building causing collateral damage such as roof failures. It was also observed that in areas of tall buildings a channeling of the wind occurred, creating an isolated path of damage. This is an important observation to take into consideration when developing urban areas with tall buildings The Portofino Towers is an example of a building which was constructed to the new criteria. It is a 44-storey building built in 1997 to the Miami- Dade County requirements for High-Velocity Hurricane Zones. After Hurricane Wilma the building including the glazing system did not sustain any significant damage. In comparison, the Greensburg building was not built to the new codes and sustained significant damage with many broken windows – refer to Figure 1.

Portofino Tower　　　　Greensburg Building

Figure 5: Portofino Tower vs Greenburg Building (Code vs no Code)

7. 2017 Hurricane season

The 2017 hurricane season was the fifth most active in the Atlantic Ocean since records commenced in 1851, with 17 named storms with multiple category 5 hurricanes occurring. Two of these hurricanes Irma and Harvey impacted the US - Irma in Florida and Harvey in Texas. These hurricanes have provided another opportunity to understand the effectiveness of the impact glazing codes. Hurricane Harvey hit Texas on August 25, 2017 between Port Aransas and Port O'Conner as a category 4 storm. Port Aransas damage was caused primarily by wind-borne debris. Several buildings in Port Aransas were affected by wind-borne debris however many did not have impact glazing systems and suffered significant damage. One Condo complex mandated that all owners must install hurricane windows and sliders. After Harvey, the condominium complex sustained no structural damage and was able to allow residents back within 4 days once power was restored. Other condominiums that did not have the same impact glazing systems will take at a least a year to reopen. As a result, other condominiums are now following and mandating owners replace existing glazing with hurricane impact glazing systems. Hurricane Irma made landfall in the Florida Keys as a powerful category 4 hurricane on September 10, 2017 with 130 mph (209 KPH) winds. In the time since Charley and Wilma in 2005, the Florida Building Commission had made some changes to wind requirements based on damage assessments. The consensus was that he codes were over engineered in some parts of the state adding unnecessary cost. As a result, wind loads were reduced by 20% in much of the state but increased in South Florida. Initial assessment of the effectiveness of the codes have shown to be very positive. Further assessments are still being conducted.

8. Council on Tall Buildings Research Project – 2017-2018

In 2017 the Council on Tall Buildings and Urban Habit (CTBUH) completed a 12-month research project funded by the Kuraray Company on 'Cyclone-Glazing and Façade Resilience for the Asia Pacific Region'. The conclusions reached were that cyclones, also referred to around the world as typhoons or hurricanes, are a major threat to the future economic stability of many developing Asia-Pacific countries and that there is a need to pre-emptively establish standards and codes in these countries to mitigate damage from wind-borne debris. Stage 2 of this research in 2018 will identify the most optimal strategies used in the construction of cyclone-resistant structures. This research will examine specific case studies in four cyclone-prone jurisdictions – Australia, Hong Kong, Japan and the Philippines.

9. Conclusions

Development in areas prone to severe weather has been increasing and this greatly increases the risk of financial and human losses. It is important to learn lessons from past weather events and develop strong codes and standards that make these infrastructures more resilient to severe weather threats to minimize both the economic and human losses. The development of hurricane impact glazing systems in Florida has proven to be highly effective at reducing the damage to buildings during hurricanes. This has a great impact on communities by reducing the time to return to normal operations. There is often resistance to building code improvements as typically they come with higher cost to the building owner. It is estimated that wind codes could add 1 to 5 percent to the home price. Insurance companies can play a positive role by providing incentives to building owners, as this will reduce their risk as well. Codes must also be put in place that balance the cost versus meeting the protection level needed. If codes are written that are over engineered then the solutions will be cost prohibitive limiting the adoption and leaving communities vulnerable to the effects of storms. This influences the resiliency and quality of life in communities after cyclonic events.

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