Cyclone-Resistant Façades
Best Practices in Australia, Hong Kong, Japan, and the Philippines

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Additional information was obtained through meetings with a considerable number of experts in the façade industry, which were conducted during the two years of this project. CTBUH would like to thank all the professionals who took time assist with this research. Some contributed by sharing their knowledge on cyclone-glazing solutions and their respective local markets, while others provided building case studies or peer-reviewed the entire publication. All of these important professionals, are highlighted on page 5.

Parts of this publication have been published as outlined below:


This study provides a worldwide overview on the current best practices regarding cyclone-resistant glazing solutions for building envelopes located in cyclone/hurricane/typhoon-prone areas. Building case studies present technical solutions that have been adopted within four specific regions in the Asia-Pacific region. Furthermore, references for the current design requirements and mandatory testing procedures for 12 jurisdictions in Asia and Oceania are presented. The ongoing research activities being undertaken by the government, façade industry, and academic institutions on this specific topic are briefly discussed, and the possible future steps are highlighted in this research report.
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Due to climate change, the number and the strength of strong wind-related events are increasing worldwide (Prevention Web 2018). There have been several initiatives undertaken by individual countries and global organizations to establish rules with the aim of containing climate change (IPCC 2018) and, subsequently, the growth of such disaster events.

In 2018 alone, numerous tropical cyclones have been recorded. Based on recorded data, the Asia-Pacific region is the most prone to these events (World Bank Group 2017). Depending on the location in which they occur, these cyclones could be also referred to as “typhoons” or “hurricanes”. They can cause considerable loss in terms of injury to people, as well as building and property damage (CNN 2018). They are presented here in order of occurrence.

Typhoon Jebi hit the Asia-Pacific region in late August and early September 2018, starting in Taiwan, where it caused large waves that resulted in six fatalities in the Yilan County. It was the most intense storm to pass through Japan in the past 25 years (CNN 2018), breaking the historical records of 10-minute maximum sustained winds. Jebi reached Japan on September 4, causing 11 deaths and more than 600 injuries in the Kansai region. Also, facilities such as the Kansai International Airport and Kyoto Station had to be shut down. The post-disaster event assessment estimated US$5.5 billion in damages (Insurance Journal 2018).

Later in September 2018, a Category 5 super-typhoon was recorded, with ten-minute sustained winds at 215 km/h, referred to as Mangkhut by the Japan Meteorological Agency (JMA) and Ompong by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). It formed near the Marshall Islands on September 7, before moving to the North of the Philippines, where it made landfall on September 14, and then crossed the South China Sea towards Hong Kong, not losing its energy until reaching the mainland of China on September 17. Mangkhut caused 134 fatalities: 127 in the Philippines, six in mainland China, and one in Taiwan. It was the strongest typhoon to hit Hong Kong in the past 50 years and many design considerations have had to be made since this Category 5 super-typhoon affected the city (Mühr et al. 2018).

Typhoon Trami, a Category 5 super-typhoon, made landfall in the Japanese Wakayama Prefecture on September 30, where it fortunately decreased to a Category 2 typhoon.

In late September 2018, in the waters near Pohnpei Island in the Federated States of Micronesia, a tropical disturbance formed and, in the next days, it exponentially grew as it moved westward. It continued becoming stronger and, on October 2, a Category 5 super-typhoon (with 10-minute sustained winds at 195 km/h), which came to be known as Kong-rey, was recorded by the JMA. The first damages were reported in the South Korean city of Tongyeong, in the South Gyeongsang Province, making landfall on October 6. During the same day, Kong-rey turned...
into an extra-tropical cyclone while transitioning, and made landfall on the southern part of the Hokkaido Island in Japan. As a result of Kong-rey's outer rain bands, four people were killed, and more than 12,000 homes in Nagasaki were left without electricity.

This data only refers to the Category 5 super-typhoons that began in September 2018 in the Asia-Pacific region. The historic wind-speed records were broken for two of the most densely populated jurisdictions in the world (Hong Kong and Kansai). The number of people who were affected — and continue to suffer from the damage — is huge, and it is these jurisdictions' responsibility to ensure safety and reduce damage as much as possible.

The envelope is the primary barrier to protect a tall building and its occupants from these external threats, in addition to controlling a building's internal climate and lighting. The failure of glazed enclosures, caused primarily by flying debris during a typhoon, represents a potential threat for occupants and is a significant contributor to the post-event recovery costs (South China Morning Post 2018b).

Even if there are no objects in the urban environment that could potentially fly during a strong wind event, urban trees and plants could fall or disintegrate, impacting the façades. In Hong Kong, after Typhoon Mangkhut, 46,000 felled trees were collected (South China Morning Post 2018a). This statistic highlights the rationale for glazing systems that are proven to be effective, and that could be certified as "cyclone-resistant," according to specific standard test procedures. This research investigates the current best practices and glazing technologies, worldwide, that have been adopted for a building envelope to withstand the impact caused by windborne debris during a strong wind event, such as a typhoon.
1.0 Research Objectives, Methodology, and Steps

1.1 Introduction

Highly-populated areas in Southeast Asia, including the Philippines, South and East China, Korea, and Japan, have been affected by typhoons, which are of such magnitude that they threaten the economic stability and growth of these regions. Additionally, the megacities that are forming in these areas demand additional residential and office space, which calls for the construction of high-rise buildings (Mejorin et al. 2018).

Over the past decade, the Asia-Pacific region has seen unprecedented growth in terms of its economy and its urban population. As growth in this area occurs, the demand for additional high-density residential and office space has also increased, resulting in record numbers of high-rise buildings being constructed, concentrated primarily in urban areas (CTBUH 2016). The urban growth in this region has largely occurred in coastal areas, which unfortunately are becoming increasingly vulnerable to typhoons.

This research report presents the norms and standards of the major tall building markets in 12 jurisdictions within the Asia-Pacific regions (including Australia and New Zealand), for the impact of flying debris on curtain walls during strong wind events in the urban environment.

This study looked for international codes and standards, and sought to examine how their adoption in different jurisdictions has spread, in order to highlight the effectiveness of existing solutions for the specific issue of flying debris resistance during major wind events (ASCE 2018). After Hurricane Andrew occurred in the United States in 1992, the Florida Building Code developed curtain wall provisions, so as to limit damage caused by high-velocity winds (ICC 2014a). This code still represents the most demanding building standard in the United States when it comes to impact-resistant façade systems.

The local requirements for protecting façades from flying debris, both in the Asia-Pacific region and worldwide, are compared in this document, and the main differences between existing standards on this specific theme are discussed.

Moreover, four Asia-Pacific jurisdictions are discussed, in order to further delve into specific problems for new curtain walls: the façade design, realization and testing processes for Australia, Hong Kong, Japan, and the Philippines are presented. The roles of the various government institutions were examined, both in their definition of the required façade performance and the subsequent approval process for curtain walls. The information presented here is intended to provide understanding of the local markets, and the respective hierarchies of the various professionals involved in façade design and realization.

Many regions evaluate the amount of damage that has occurred due to a cyclone in terms of deaths; the amount of buildings and infrastructure to be repaired; the total economic impact; and the possible mitigation actions to be undertaken (Ginger et al. 2010; Boonyapinyo 2010; Duy et al. 2007; Yimin et al. 2012). Videos and photos depicting the impact of strong winds on our cities and countries are now frequently appearing on television and news outlets (see Figure 1.1) (Nikkei 2018, BBC 2018, The Irish Times 2018, NBC News 2018, Miami Herald 2018).

The bond between the modern, conventional skyscraper and glazing is evident; the typical tall building design seeks to deploy as much glass as possible (Mori 2015). Although the building’s design aims to achieve a transparent and lightweight image, it still must adhere to safety regulations and guarantee resiliency against the effects of natural events.

A comparison between the number of tall buildings in a cyclone-prone area, the number of tall buildings hit by past cyclone events, the number of tall buildings that are currently “at risk,” and the total number of tall buildings of a certain height range within these regions is provided (World Bank Group 2017).

Curtain wall systems are not simply used to define a building’s appearance; they form the true skin of the building. Like the skin on a living body, a building’s curtain wall is the barrier between the indoor environment and the exterior. A building’s façade is designed to control the indoor climate, allow natural light in, and to some extent, allow the building to take advantage of natural ventilation. However, in many circumstances, the curtain wall becomes a barrier (Taywade 2015), protecting the building and its occupants from...
external threats, such as rough climates, violent attacks (Clift 2006), and windborne objects (Shah 2009).

Building solutions have already been found, and façade technologies developed, to reduce building damage caused by the impact of flying debris. The effectiveness of cyclone-resistant façades against past cyclone events is proven (Miami-Dade County Building Code Compliance Office 2006), and evidence to support the goal of further advancing cyclone-resistant façades is presented in this document.

This technical publication is intended to be used as a reference document for industries and professionals in the design and renovation of curtain walls, and as a means of presenting tangible examples of the existing best practices in the Asia-Pacific region to developers and building owners.

1.2 Research Objectives

The ultimate objective of this research is to provide a tool for professionals operating in the façade engineering discipline, when considering buildings located in cyclone-prone areas of the Asia-Pacific region.

This report aims to serve as a reference document to compare international and Asia-Pacific local codes and standard procedures on the topic of flying debris resistance. The differences in roles and responsibilities of various experts involved in the façade definition are described, highlighting the dissimilarities between the selected Asia-Pacific local markets.

Furthermore, the preponderance of tall buildings in cyclone-prone locations in the Asia-Pacific region is such that an examination of the destructive potential of such events and the state-of-the-art techniques underscores the scale of the global risk and range of responses. The research project primarily seeks to answer the questions:

- What buildings are generally protected against typhoons?
- Also, which are the best practices adopted for the most recent building façades in Australia, Hong Kong, Japan, and the Philippines?

The main risks of these construction types are highlighted, as well as the most suitable technical solutions to prevent façade failure in case of a cyclone event. By avoiding glass breakage and flying debris penetration into the building, the property losses stemming from these events can be minimized. Likewise, rain penetration and mold formation can also be avoided.

To conclude the discussion, existing building case studies serve as reference examples to share the current best practices within the selected Asia-Pacific jurisdictions, which exceed the
2.1 Tropical Cyclones

Tropical cyclones are rapidly rotating storm systems that produce strong winds and heavy rain. They originate almost exclusively over tropical seas. Viewed from overhead, a clear “eye” of the storm can be identified as the center of the spiral arrangement of wind, blowing counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. They grow over large bodies of relatively warm water through water evaporation from the ocean surface, which condenses into clouds and rain. This occurs when air moisture rises and saturates. Cyclones have different names depending on the geographical area in which they occur. They are called “hurricanes” in the Atlantic Ocean, Caribbean Sea, Gulf of Mexico and east of the International Date Line; “cyclones” in the Southwest Pacific Ocean; and “typhoons” west of the International Date Line in the Pacific Ocean (see Figure 2.1 and Table 2.1). These events threaten the safety of one billion people every year, through the effects of violent precipitation and devastating wind (World Bank Group 2017). The resulting windborne debris can be source of façade damage during these events (see Figure 2.2).

These disaster events differ from typical European storms due to their diameter, which can range between 100 and 2,000 kilometers wide. The rotating winds conserve their angular momentum while flowing, traveling large distances without losing any energy (Montgomery & Farrell 1993). The period of the year in which they normally occur is the late summer, when the difference between the temperature of the air and the sea surface is higher.

The geographic area most affected by these events is the Asia-Pacific region. The World Bank Group, in its October
## Table 2.1: Tropical cyclone classifications, used by the official warning centers worldwide. NHC, CPHC, and JTWC use one-minute sustained wind, the IMD uses three-minute sustained wind (not shown in the table), while all other warning centers use 10-minute sustained winds. The regional differences in classifications are shown.

<table>
<thead>
<tr>
<th>Beaufort Scale</th>
<th>1-minute sustained winds</th>
<th>10-minute sustained winds</th>
<th>NE Pacific &amp; N Atlantic</th>
<th>NW Pacific</th>
<th>N Indian Ocean</th>
<th>SW Indian Ocean</th>
<th>Australia &amp; S Pacific</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–7</td>
<td>&lt;32 knots (37 mph; 59 km/h)</td>
<td>&lt;28 knots (32 mph; 52 km/h)</td>
<td>Tropical Depression</td>
<td>Tropical Depression</td>
<td>Depression</td>
<td>Zone of Disturbed Weather</td>
<td>Tropical Disturbance</td>
</tr>
<tr>
<td>7</td>
<td>33 knots (38 mph; 61 km/h)</td>
<td>28–29 knots (32–33 mph; 52–54 km/h)</td>
<td>Tropical Depression</td>
<td>Tropical Depression</td>
<td>Deep Depression</td>
<td>Tropical Disturbance</td>
<td>Tropical Depression</td>
</tr>
<tr>
<td>8</td>
<td>34–37 knots (39–43 mph; 63–69 km/h)</td>
<td>30–33 knots (35–38 mph; 56–61 km/h)</td>
<td>Tropical Storm</td>
<td>Tropical Storm</td>
<td>Tropical Storm</td>
<td>Cyclonic Storm</td>
<td>Tropical Low</td>
</tr>
<tr>
<td>9–10</td>
<td>38–54 knots (44–62 mph; 70–100 km/h)</td>
<td>34–47 knots (39–54 mph; 63–87 km/h)</td>
<td>Tropical Storm</td>
<td>Tropical Storm</td>
<td>Severe Tropical Storm</td>
<td>Severe Cyclonic Storm</td>
<td>Category 1 Tropical Cyclone</td>
</tr>
<tr>
<td>11</td>
<td>55–63 knots (63–72 mph; 102–117 km/h)</td>
<td>48–55 knots (55–63 mph; 89–102 km/h)</td>
<td>Category 1 Hurricane</td>
<td>Typhoon</td>
<td>Very Severe Cyclonic Storm</td>
<td>Tropical Cyclone</td>
<td>Category 3 Severe Tropical Cyclone</td>
</tr>
<tr>
<td>12+</td>
<td>64–71 knots (74–82 mph; 119–131 km/h)</td>
<td>56–63 knots (64–72 mph; 104–117 km/h)</td>
<td>Category 2 Hurricane</td>
<td>Typhoon</td>
<td>Extreme Tropical Cyclone</td>
<td>Intense Tropical Cyclone</td>
<td>Category 4 Severe Tropical Cyclone</td>
</tr>
<tr>
<td></td>
<td>72–82 knots (83–94 mph; 133–152 km/h)</td>
<td>64–72 knots (74–83 mph; 119–133 km/h)</td>
<td>Typhoon</td>
<td>Typhoon</td>
<td>Extremely Severe Cyclonic Storm</td>
<td>Intense Tropical Cyclone</td>
<td>Category 4 Severe Tropical Cyclone</td>
</tr>
<tr>
<td></td>
<td>83–95 knots (96–109 mph; 154–176 km/h)</td>
<td>73–83 knots (84–96 mph; 135–154 km/h)</td>
<td>Category 3 Major Hurricane</td>
<td>Typhoon</td>
<td>Super Typhoon</td>
<td>Very Intense Tropical Cyclone</td>
<td>Category 5 Severe Tropical Cyclone</td>
</tr>
<tr>
<td></td>
<td>96–97 knots (110–112 mph; 178–180 km/h)</td>
<td>84–85 knots (97–98 mph; 156–157 km/h)</td>
<td>Typhoon</td>
<td>Typhoon</td>
<td>Super Typhoon</td>
<td>Super Cyclonic Storm</td>
<td>Category 5 Major Hurricane</td>
</tr>
<tr>
<td></td>
<td>98–112 knots (113–129 mph; 181–207 km/h)</td>
<td>86–98 knots (99–113 mph; 159–181 km/h)</td>
<td>Typhoon</td>
<td>Typhoon</td>
<td>Super Typhoon</td>
<td>Super Cyclonic Storm</td>
<td>Very Intense Tropical Cyclone</td>
</tr>
<tr>
<td></td>
<td>113–122 knots (130–140 mph; 209–226 km/h)</td>
<td>99–107 knots (114–123 mph; 183–198 km/h)</td>
<td>Category 4 Major Hurricane</td>
<td>Typhoon</td>
<td>Super Typhoon</td>
<td>Very Intense Tropical Cyclone</td>
<td>Category 5 Major Hurricane</td>
</tr>
<tr>
<td></td>
<td>123–129 knots (142–148 mph; 228–239 km/h)</td>
<td>108–113 knots (124–130 mph; 200–209 km/h)</td>
<td>Super Typhoon</td>
<td>Super Typhoon</td>
<td>Super Typhoon</td>
<td>Very Intense Tropical Cyclone</td>
<td>Category 5 Major Hurricane</td>
</tr>
<tr>
<td></td>
<td>130–136 knots (150–157 mph; 241–252 km/h)</td>
<td>114–119 knots (131–137 mph; 211–220 km/h)</td>
<td>Super Typhoon</td>
<td>Super Typhoon</td>
<td>Super Typhoon</td>
<td>Very Intense Tropical Cyclone</td>
<td>Category 5 Major Hurricane</td>
</tr>
<tr>
<td></td>
<td>&gt;137 knots (158 mph; 254 km/h)</td>
<td>&gt;120 knots (140 mph; 220 km/h)</td>
<td>Category 5 Major Hurricane</td>
<td>Category 5 Major Hurricane</td>
<td>Category 5 Major Hurricane</td>
<td>Category 5 Major Hurricane</td>
<td>Category 5 Major Hurricane</td>
</tr>
</tbody>
</table>

Since the mid-1960s, there has been an attempt to codify the impacts of strong winds on structures, with the determination of return periods based on limited data of wind gusts in tropical regions of Australia (Holmes, Kwok & Ginger 2012). Previous to this, in 1952, the Standards Association of Australia (SAA) published the Int. 350 Minimum Design Loads on Structures (SAA 1952). This document started the practice of “referenced documents” in building regulations, and it was in effect until there was a change in designation to AS 1170 (SAA 1971), which is still in place today (Pham 2007). The Int. 350 is the first Australian national loading specification issued in the absence of any national building regulation.

In the early morning of Christmas Day, December 1974, the city of Darwin, in the Northern Territory, was hit by Tropical Cyclone Tracy and suffered massive damage and loss of life (Walker 2010) (see Figure 3.1). The anemometer at Darwin Airport recorded a gust of 217 km/h before the recording failed. Estimates based on previous readings suggest that peak gusts associated with Tracy were most likely in the range of 217 to 240 km/h, corresponding to maximum mean winds (10-minute average) of 140 to 150 km/h. This was among the most destructive storms ever recorded in Australia, after Severe Tropical Cyclone Althea, which hit Townsville, Queensland in 1971 (see Figure 3.2). This was not the first time Darwin had been severely damaged by a cyclone: it was also hit in January 1897 and March 1937.

As a result, more focus was placed on improving the performance and integrity of structures in areas subject to extreme winds in cyclonic areas (Mason & Haynes 2010b) because it was evident that the damage to glazing systems, caused by windborne debris, represented a serious threat to the safety of building occupants during storms, and could contribute significantly to post-event recovery costs (Murphy 1984).

With the establishment of the Commission, the Darwin Area Building Manual of 1975 introduced the general requirement to test any material used or proposed to be used in construction...
of a building, and potentially prohibit the use of materials not compliant with the requirements of the manual or found to be unsuitable or unfit for the purpose. It is also stated under the manual’s structural provisions that, where a material or form of construction is not covered by an Australian Standard, test evidence carried out by a laboratory registered by National Association of Testing Authorities may be accepted. This influenced Australia to develop a technically upgraded solution to protect windows from flying debris in strong-wind conditions.

With particular focus on doors, windows and cladding, the manual stated that the protection of openings is considered adequate if it has demonstrated the capability to resist a 4-kilogram mass having a 50-by-100-millimeter impacting cross section striking at any angle, at a velocity of 20 m/s, without affecting internal design pressure. When subjected to a test, the glazing could be fractured, but had to withstand the impact, which represents an energy of 800 Joules without penetration. The cracked glass was then subjected to the full design wind pressure applicable to the cyclonic region. The cracked glass should be able to resist the pressure without any air leakage, provided the edges of the glass were properly held to the frame using an adhesive glazing compound. That is, the critical part of the design was not only the glass being adequate, but also the cracked glass needed to adhere to the frames to prevent the entire glass panel being forced out of the supporting frame. This can be considered the first “cyclone-resistant glazing”.

Innovative testing of glass was developed in a laboratory in Pilkington, Australia in 1975. This testing procedure became the basis in the development of modern standards to address impact resistance from windborne debris loading. Subsequently, in 1977, the Australia Bureau of Meteorology, Department of Sciences, published the Report on Cyclone Tracy, December 1974 (ABM 1977).

The guidelines defined within the Darwin Area Building Manual were not mandatory for all the Australian cyclone-prone regions and, as a consequence, these were not widely adopted, because the designers felt them too conservative for lower-risk areas (Walker & Reardon 1987).

In 1978, the Experimental Building Station, Department of Construction published Technical Record (TR) 440, Guidelines for the Testing and Evaluation of Products for Cyclone-Prone Areas (EBS 1978). It was issued as an outcome of a workshop, where the subject of discussion was the weak adoption of the standard testing procedures set forth by the Darwin Area Building Manual. The TR 440 focused on two main areas: “the nature of winds and the response of buildings and building components to them; and the development of valid methods of performance testing” (EBS 1978). The aim of these modifications to the impact speed was to ensure the
4.1 Façades in Cyclone-Prone Areas – Main Threat: Flying Debris

The major threat to façades in severe storms is represented by the windborne debris that could potentially impact the glazing system and create an opening in the building envelope. This failure would increase internal pressurization and, in this way, the other outer walls could potentially collapse if the structure is not designed to sustain the high wind pressure of a typhoon event. Furthermore, when the building envelope breaks, a typical follow-on event is the detachment of the roof. Another consequential effect is damage from wind-driven rain penetrating the building’s interior.

The volume and effect of windborne debris, according to the current best practices in terms of code and standard testing, varies based on the building location, maximum wind speed, and height. It is evident that the potential debris sources are also related to surrounding constructions and vegetation (plants, trees, etc.), and other sources of debris, such as trash bins, signs, and so on.

Several international studies have been conducted that aim to understand the effects of various debris sources (Maruyama et al. 2013). Furthermore, calculating the risk from flying debris in typhoon events is very complex (ASCE 2018). Data variables in that risk calculation include: the ability of a structure to absorb flying debris impact; the impact energy; and the trajectory of the debris flight. These factors also vary depending on the intensity of the typhoon event.

The unpredictable occurrence of these disaster events does not allow for precise estimation of the possible loss, and it presents an obstacle for developers and building owners to calculate the return on their investments in typhoon-resistant façade solutions.

The typical debris in a typhoon include missiles (tree branches, fences, etc.), roof gravel, roof tiles, signage, portions of other damaged structures carried on the wind, and metal sheets. The impact energy has to be absorbed by the façade system if building failure is to be prevented. The flying debris does not have to penetrate the façade to cause building failure, therefore, “in windborne-debris regions, door and window assemblies must be specified to resist test missile loads specified in ASTM E1996-14a (ASTM 2014)” (ASCE 2018).

4.2 Cyclone-Resistant Façades – Main Characteristics

Façade resilience is needed to provide adequate safety during a typhoon event. This characteristic aims primarily to avoid broken glass. When breakage occurs, the glass could injure people and, in order to avoid this, requirements for tempered glass should be introduced. Further, the whole façade system needs to be designed properly. During a wet disaster event such as a typhoon, if the glass breaks, inevitably the internal property loss could carry a significant recovery cost in terms of furniture, electronic devices and documents. The framing system design and the installation of the glass in the framing system are two important components that need to be analyzed and properly designed.

The frame is commonly designed to avoid the glass being ejected from this retaining system when subjected to high wind pressure. In this perspective, the curtain wall frame is stronger, compared to a façade not exposed to typhoon winds. Furthermore, the glass bite is normally deeper, in order to let the façade system work as a unit (consisting of glass, sealant, and frame) with the aim to protect interiors from atmospheric threats.

If the aim is that a glazing system be effective in mitigating damage from windborne debris, the entire system needs to be designed properly to resist the storm event. All the window and curtain wall components (the framing system and the glass installation within that system) must be designed to perform during a cyclone event. When designing glazing systems, it is important to understand what kind of wind loads the building will experience. The impact test requirement will be determined by building location and wind zone. The pressure cycling required will be determined not only by the wind zone region, but also by the shape, height, and location of the building, both in relation to other buildings and the size of the window itself. This becomes more important in
urban settings, where the wind loads can increase due to the surrounding buildings, resulting in a wind-tunneling effect.

Laminated glass could be defined as “cyclone glass” when it guarantees a precise level of performance. The composition used in typhoon-resistant glass must resist both the wind load and the missile impact specified by codes. The thickness of the glass lites in the laminated glass is determined by the wind load and the interlayer type. However, resistance to penetration by missile impact is determined by the interlayer type and the thickness of the interlayer. The interlayer thickness relates to missile impact speed, not to design wind load. It works by coupling two or more lites of glass with one or more interlayer elements (see Figure 4.1). This guarantees glass retention if breakage occurs. The main interlayer types are polyvinyl butyral (PVB) and ionoplast.

Both PVB and ionoplast interlayers have been used successfully in laminated glass for hurricane glazing systems. PVB is a soft interlayer and works well when the design pressure is lower and the missile size is smaller. Because of the low stiffness, laminates using PVB tend to not perform well when the design pressure is high. The high wind pressures can cause the laminate to pull out of the frame during the cycling portion of the test, and therefore typically will need better frame design or a thicker interlayer and/or glass. The laminate is at risk of becoming detached with high wind pressures during the final pressure cycling testing (ASTM 1996).

Ionoplast was introduced in 1998 in South Florida; it can meet the highest performance criteria required for impact resistance (large missiles D and E from ASTM E1886 and ASTM E1996). Being a stiff interlayer, it provides added strength and rigidity, and remains intact after the pressure cycling test. This could potentially allow a lower grade of glass to be used, saving costs. Another advantage of the ionoplast interlayer is the possibility it gives to the glazing system to be dry-glazed, reducing installation costs and time, as compared to the traditional wet-glaze system installation. It is not possible to design a dry-glaze system with laminated glass that uses PVB interlayers, because the resulting product will be too flexible. Table 4.1 illustrates the differences between the three kinds of window assemblies. See Figure 4.2 for an example of an ionoplast installation.

However, in the testing for the product approval process, the aim is not just to test the components, but the whole system. In this way, the glass can be pre-dimensioned based on the size of the specimen and the impact velocity of the missile, but it is necessary to

<table>
<thead>
<tr>
<th>Type of Assembly</th>
<th>Description</th>
</tr>
</thead>
</table>
| Typical Construction | • 6-mm heat-strengthened (HS) glass + 2.28-mm interlayer + 6-mm HS glass for large missile impact  
• 6-mm HS glass + 1.52-mm or 0.89-mm interlayer + 6-mm HS glass for small missile impact |
| Polyvinyl Butyral (PVB) | • Typically used in 2.28 mm thickness for relatively small glass panel sizes and low pressures in large missile-impact resistance applications  
• Small missile-impact resistance typically uses a 1.52 mm thickness  
• Available in clear or colored tint  
• UV-filtering |
| Ionoplast | • Typically used for high design pressures, large windows, and large missile impacts  
• Can be used in dry-glaze systems - lower cost and easier installation  
• High-modulus interlayer used to bond two lites of glass together  
• 10x stiffer than PVB, 5x more tear-resistant  
• Thicknesses include 0.89 mm, 1.52 mm, 2.28 mm  
• UV-filtering  
• UV-transparency available  
• Available in clear or translucent white  
• Less sensitive to moisture intrusion at the laminate edge than PVB |

Table 4.1. Typical window assembly descriptions and cyclone-resilience capabilities.
Australia was the world's first developer of standards and building technologies, which facilitated the realization of cyclone-resistant façades capable of withstanding the impact of flying objects in strong wind conditions. The current Australian requirements for cyclone-resistant façade certification has changed recently. These are now stricter than related standards in the United States when it comes to impact-testing missile speed, but the testing procedures can be perceived as ambiguous. This has had a negative impact on the basic adoption of cyclone-resistant glazing systems. CTBUH wishes to highlight that, even though the projectile velocities in Australia are significantly higher than those in the United States, unlike the US, there is no requirement to check the adequacy of the glazing to resist wind pressure after the impact.

5.1 Principal Design Rules

Current Australian building codes do not require the external building fabric to be resistant to windborne debris, unless the building internal pressure is to be reduced in accordance with AS/NZS 1170.2:2011, Clause 5.3.2, i.e., ignoring the possibility of a dominant opening.

Australia has introduced some requirements for the design of curtain walls, which must guarantee performance against the effects of strong wind on a building. The first building code for protection from windborne debris in cyclones was put in place shortly after Cyclone Tracy devastated the city of Darwin on Christmas Eve, 1974 (Darwin Reconstruction Commission 1975). The approved strategy to protect against debris was defined as the ability to prevent a 100- by 50-millimeter, 4-kilogram timber missile traveling at 20 m/s from causing a significant opening. Although the Pilkington ACI Company launched “Triplex” 13.8-millimeters cyclone-resistant glass in January 1977, this product was aimed at preventing failure of roofs experiencing cyclic pressures, and was not focused 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 Commonwealth Department of Construction, and published in TR 440 in July 1977. This document recommended an impact speed of 15 m/s for the 4-kilogram timber missile. This debris impact requirement was adopted in the 1989 revision of the AS 1170.2-1989 SAA Loading Code.

Since the development of the first drafts of requirements in Australia, various studies have been conducted, and standards for hurricane protection were developed in the United States. In Australia, there is one fundamental requirement that is still referenced, which aims at reproducing the effects of flying debris during tropical cyclone events that could potentially impact a building envelope. This is the loading requirement presented in the AS/NZS 1170.2:2011 Structural Design Actions – Wind Actions, which takes into account the location of the building and the related regional velocity of the wind, the level of importance for the building, and the level of protection.

Cyclic pressure testing following missile impact was omitted.

Based on this data, the weight and the velocity of the projectile for the impact test simulations were defined. In 2011, a change was made to AS/NZS 1170.2 to increase the projectile speed from 15 m/s to 0.4 of the regional velocity (see page 49). The basis for this increase was derived from conclusions obtained during wind studies in the United States where a 4-kilogram timber missile picked up by a 69 m/s wind gust could accelerate from 0 to 15 m/s in less than 2 meters (Lin et al. 2007).

The increase in missile speed in AS/NZS 1170.2:2011 has greatly increased the cost of glass and framing in order to meet the new requirements. As a result, buildings are being built without the use of impact glazing, and windows that fail can allow rain, wind, and debris to enter the interior, causing significant damage to buildings and their contents, and potentially cause injury or death to occupants.

Depending on the building location, the façade is always tested to guarantee many other performance specifications, not just flying-debris resistance. However, one issue that was highlighted in the most recent post-cyclone reports is that the current systems allow water penetration during strong wind conditions (CTS 2017). In Australia, the results of the cladding tests do not have to be presented to any government institution in most cases. As a result, glazing protection (laminated glass or well-designed and thoroughly-tested shutters) is still falling short of what is needed in tropical regions of Australia.
There are other conditions in which the requirement is different. The debris impact-resistant façades in the Northern Territory and the state of Queensland often require a registered engineer’s certificate confirming the façade meets the debris-impact test requirements. The client, client’s certifier, or client’s representing consultant typically requires a debris-impact test report to be presented.

The reference requirements can be found in the following local standards (see Tables 5.1 & 5.2). Technical Note No. 4 could be chosen as a standard testing procedure (CTS 2017).

### 5.2 Professional Roles and Responsibilities

**Developers**
Australian developers have to deal with the local rules in cyclone-prone regions C and D (see Figure 5.1). The AS/NZS 1170.2:2011 Structural Design Actions – Wind Actions has indicated the appropriate impact resistance for the building envelope, depending on the precise location of the building and the regional velocity of the wind. Developers rely on advice from consultants hired on the projects during design documentation, and ultimately the façade contractors, who are providing the design and construction (D & C) service. Specialist façade contractors are also required to certify the design/engineering, fabrication and installation of façade products.

Façade solutions/shutter systems are certified to guarantee precise levels of performance in case of a cyclone event. Moreover, the importance of these building technologies, and their ability to protect the private/public property in case of a cyclone event is highlighted by the reports issued by government authorities.

Developers and building owners are also the professionals that deal with the

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<table>
<thead>
<tr>
<th>Rise in Stories</th>
<th>Class of Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 OR MORE</td>
<td>A, A</td>
</tr>
<tr>
<td>3</td>
<td>A, B</td>
</tr>
<tr>
<td>2</td>
<td>B, C</td>
</tr>
<tr>
<td>1</td>
<td>C, C</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Class of buildings</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>A single dwelling being a detached house, or one or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house, or villa unit.</td>
</tr>
<tr>
<td>1B</td>
<td>A boarding house, guest house, hostel or the like with a total area of all floors not exceeding 300 m², and where not more than 12 reside, and is not located above or below another dwelling or another Class of building other than a private garage.</td>
</tr>
<tr>
<td>2A</td>
<td>A building containing 2 or more sole-occupancy units each being a separate dwelling.</td>
</tr>
<tr>
<td>2B</td>
<td>A residential building, other than a Class 1 or 2 building, which is a common place of long term or transient living for a number of unrelated persons. Example: boarding house, hostel, backpackers’ accommodation or residential part of a hotel, motel, school or detention center.</td>
</tr>
<tr>
<td>3</td>
<td>A dwelling in a building that is Class 5, 6, 7, 8, or 9 if it is the only dwelling in the building.</td>
</tr>
<tr>
<td>4</td>
<td>An office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8, or 9.</td>
</tr>
<tr>
<td>5</td>
<td>A shop or other building for the sale of goods by retail or the supply of services direct to the public. Example: café, restaurant, kiosk, hairdressers, showroom, or service station.</td>
</tr>
<tr>
<td>6</td>
<td>A building which is a car park.</td>
</tr>
<tr>
<td>7A</td>
<td>A building which is for storage or display of goods or produce for sale by wholesale.</td>
</tr>
<tr>
<td>7B</td>
<td>A laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing or cleaning of goods or produce is carried on for trade, sale, or gain.</td>
</tr>
<tr>
<td>9</td>
<td>A building of a public nature.</td>
</tr>
<tr>
<td>9A</td>
<td>A health care building, including those parts of the building set aside as a laboratory.</td>
</tr>
<tr>
<td>9B</td>
<td>An assembly building, including a trade workshop, laboratory, or the like, in a primary or secondary school, but excluding any other parts of the building that are of another class.</td>
</tr>
<tr>
<td>9C</td>
<td>An aged care building.</td>
</tr>
<tr>
<td>10</td>
<td>A non-habitable building or structure</td>
</tr>
<tr>
<td>10A</td>
<td>A private garage, carport, shed, or the like.</td>
</tr>
<tr>
<td>10B</td>
<td>A structure being a fence, mast, antenna, retaining or freestanding wall, swimming pool, or the like.</td>
</tr>
<tr>
<td>10C</td>
<td>A private bushfire shelter.</td>
</tr>
</tbody>
</table>

**Table 5.2. Building classifications in Australia.** Source: National Construction Code (NCC) 2016, Vol. 1.5
6.1 Principal Design Rules

The principal guidelines for façade design in Hong Kong (see Figure 6.1) are dictated by the Hong Kong Buildings Department (BD). These differ from the requirements adopted in mainland China. Curtain walls must be designed to meet the specific requirements set out in Regulation 43 of the Building (Construction) Regulations. Further guidance on curtain wall construction comes from the 2018 Hong Kong Code of Practice for Structural Use of Glass.

In 1983, the BD released the first edition of the Code of Practice on Wind Effects in Hong Kong. Revised in 2004, this document serves as the primary reference for local façade engineers when calculating wind loads for structures in Hong Kong. The code provides a detailed explanation of the use of wind-tunnel testing with regards to identifying and localizing the peak wind zones on a building envelope. This can help avoid over-engineered solutions, identifying and localizing the areas of peak wind on the building envelope. The code explains the safety factors to be considered in wind pressure calculations and the testing procedures to be carried out, specifying design wind pressures and design wind velocities (see Table 6.1).

A second fundamental code for façade design in Hong Kong is the 2018 Code of Practice for Structural Use of Glass, in force as of 2019. The code provides guidelines on subjects such as the use of safety-laminated glass solutions for exterior building façades, when the size of the glass pane exceeds 2.5 square meters and any point of the glass pane is at a height of 5.0 meters or more above the finished floor level of the accessible areas on either side of the pane where tempered glass is used. Heat-strengthened glass, in principle, can still be used in lieu of laminated glass.

From the 2018 Code of Practice:

5.2 SPECIAL DESIGN REQUIREMENTS
5.2.1 Safety requirement against glass breakage
1. Laminated glass should be used in glass elements resisting long-term load, such as roof, canopy, skylight, sloped glazing, staircase, floor, beam, column, etc., and glass balustrade.
2. Tempered glass or laminated glass should be used in the parts of building exterior façade also serving as protective barrier.
3. Where tempered glass is used in building exterior façade, the glass should be in the form of laminated glass if it meets the following conditions:
   i. The size of glass pane exceeds 2.5 m²;
   and
   ii. Any point of the glass pane installed is at a height 5 m or more above the finished floor level of the accessible area on either side of the pane.
4. Where an insulated glass unit (IGU) is used in building exterior façade, the requirement in item (3) above applies to the outermost pane of the IGU only.

The BD stipulates guidelines on design submission, construction and testing of façades for private development only. Whereas government buildings and public housing are outside the jurisdiction of the Buildings Ordinance (BO), the 2018 Code of Practice promulgated by BD does serve as a major reference for design of façades in those government projects.

The BD Officer oversees new building submissions. Each new project is referred to a Registered Structural Engineer (RSE) to review all submitted drawings and calculations before any approval and consent for new building works can commence. The BD Officer will regularly consult with his senior manager for any designs that fall outside of common practices and/or HKBD Codes. For major projects, it is common to have a façade engineer who is a separate RSE.

Every step in the façade design approval process in Hong Kong has to be discussed with the BD, for its approval and consent. If a building is applying for an Occupation Permit (OP), the performance test report for the curtain wall is currently required by the BD for approval and review. The designers, together with the façade consultants (if they receive the assignment to directly deal with the BD), have to present the façade design to the BD in the form of drawings, calculations and formal interviews.

Before obtaining the completion certification of a new building (in order to receive the OP), the developer’s representatives are required to submit
Developers

Developers in Hong Kong are required to submit and present their façade design, inclusive of colored plans, calculations and application forms, to the Hong Kong BD in order to receive the authorization to start construction. Hong Kong has some of the strictest statutory regulations and approval processes in the Asia-Pacific region. This does make it a comparatively safe built environment, especially during strong-wind events. The high standards do lead to higher construction costs and potentially longer construction programs. However, these are offset by the potential yields gained by developers when selling or renting floor space upon completion. Generally, real estate developers, including those in Hong Kong, will employ a specialist façade consultant to develop the specifications and performance criteria for the façade components.

Currently, the typhoon resistance of façades is not a typical parameter for these certifications and, as previously mentioned, there are no current any performance mock-up (PMU) results, material certificates and test reports as set out by BD in the approval letter. These documents are required to prove that the design and materials used have been tested and are structurally sound.

Finally, the BD also requires a structural performance test report, conducted according to the Practice Note for Authorized Persons (PNAP) APP-37 (BD, 2012) or the 2018 Hong Kong Code of Practice for Structural Use of Glass (BD, 2018). The test is to be conducted and issued by an independent Hong Kong Laboratory Accreditation Scheme (HOKLAS) curtain-wall-testing laboratory. These are extensions to the Building Regulations, and are endorsed by the RSE to prove the proposed façade is structurally safe to the public. The endorsed test report is then submitted to the BD for obtaining the OP certificate upon completion of construction.

In recent years, there has been an increase in the requirements for sustainable construction included in specifications, through the adoption of LEED, BREEAM, and ASHRAE certification schemes. Once acquired, this certification can bring higher commercial yields for the developer, but also means that, generally, a higher quality of façade is constructed in order to achieve the energy-efficient demands of the specification. Currently, the typhoon resistance of façades is not a typical parameter for these certifications and, as previously mentioned, there are no current

### Table 6.1. Design wind pressures and hourly-mean wind velocities, relative to building heights. Source: Code of Practice on Wind Effects in Hong Kong, 2004

<table>
<thead>
<tr>
<th>Height above site-ground level (m)</th>
<th>Design wind pressure $q_v$ (kPa)</th>
<th>Design hourly-mean wind velocity $V$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 5</td>
<td>1.82</td>
<td>35.8</td>
</tr>
<tr>
<td>10</td>
<td>2.01</td>
<td>38.7</td>
</tr>
<tr>
<td>20</td>
<td>2.23</td>
<td>41.7</td>
</tr>
<tr>
<td>30</td>
<td>2.37</td>
<td>43.6</td>
</tr>
<tr>
<td>50</td>
<td>2.57</td>
<td>46.2</td>
</tr>
<tr>
<td>75</td>
<td>2.73</td>
<td>48.3</td>
</tr>
<tr>
<td>100</td>
<td>2.86</td>
<td>49.8</td>
</tr>
<tr>
<td>150</td>
<td>3.05</td>
<td>52.1</td>
</tr>
<tr>
<td>200</td>
<td>3.2</td>
<td>53.8</td>
</tr>
<tr>
<td>250</td>
<td>3.31</td>
<td>55.1</td>
</tr>
<tr>
<td>300</td>
<td>3.41</td>
<td>56.2</td>
</tr>
<tr>
<td>400</td>
<td>3.58</td>
<td>58</td>
</tr>
<tr>
<td>≥ 500</td>
<td>3.84</td>
<td>59.17</td>
</tr>
</tbody>
</table>
7.0 Japan

7.1 Principal Design Rules

In Japan, the design of a curtain wall has to guarantee performance against strong winds depending on the location. The Recommendations for Loads in Buildings (AIJ 2015) is the fundamental code referenced. This document directly refers to the building cladding and provides the references for the correct design. The principal elements to take into account for estimating wind load are: the design velocity pressure, the peak wind force coefficient, and the subject area of components/cladding.

The design velocity pressure is based on the air density and on the design wind speed, which depends on the direction of the wind. The basic wind speed is based off of a 100-year return period (AIJ 2015) and on a 10-minute mean wind speed over an open and flat terrain at an elevation of 10 meters’ height. This value changes depending on the area of Japan being examined (see Figure 7.1). The peak wind force for the design of the cladding depends on the external pressure coefficient and the factor for the effect of fluctuating internal pressures.

Although the Architectural Institute of Japan (AIJ) Recommendation gives useful information, the legal minimum requirements for wind design of curtain walls are stipulated in Ministry of Construction Public Notice No. 1458 of Ministry of Land, Infrastructure and Transport and Tourism (MLIT) of Japan. MLIT Notices are issued to implement requirements in Building Standard Law of Japan; the Enforcement Order and the AIJ Recommendation are applicable only if these give more conservative requirements than those given by the MLIT Notices. The Standard Wind Speed, which provides the basis for requirements in the Public Notice No. 1458, is the expectation for a return period of 50 years. For the purposes of code, a building in Japan is considered a “tall building” if it is higher than 60 meters (AIJ 2015).

Focusing on the flying-debris resistance of glazed building envelopes, the JIS R 3109:2018 Glass in Building – Destructive-Windstorm-Resistant Security Glazing – Test Method was established on July 20, 2018 (investigated by the Japanese Industrial Standard Committee and published by the Japanese Standards Association). Currently, glass is certified according to this industrial standard, which is based on ISO 16932; the framing system and the panel sizes are not related to any mock-up. They are standardized in order to test the glass.

Figure 7.1 Map showing the locations of 100-year mean wind speed events (in m/s), sustained for at least 10 minutes at 10 meters above ground over a flat and open terrain in winter. Source: AIJ
Currently, the 1:1-scale façade mock-ups are tested for many other performance criteria, other than typhoon resistance, such as wind pressure, earthquake resistance, water penetration, etc. The present procedure could be implemented in order to test the entire façade system’s flying-debris resistance (following a procedure such as the ASTM E1886 and ASTM E1996).

In Japan, following the testing, the results do not have to be presented to any government institute in most cases. For some cases, design documents showing that some selected important parts of the building envelope are composed of materials that provide resistance to spread of fire must be submitted to the authority having jurisdiction (AHJ). Also, calculation of energy loss and heat gain through the building envelope is required in some cases.

The Curtain Wall Performance Standard is a Japanese guideline for curtain wall design and testing. The wind load section was revised in 2017, and the recommendations correspond to the following building height ranges (see Figure 7.2 and Tables 7.1 and 7.2):

- H < 60 m: Grade 1 or 2
- H ≥ 60 m: Grade 2 or 3

### 7.2 Professional Roles and Responsibilities

**Developers**
Real estate developers in Japan typically ask curtain-wall industry professionals for higher performance, as they are the only ones effectively performing the certification processes and reports. Some dialogue with the AHJ can generate benefits for the developers. One example of this is in the instance of choosing a laminated glass solution instead of a single-layer annealed glass product.

This choice could result in the authorization to reduce the minimum setback for new constructions; this means a bigger building volume can be authorized on the same lot, because the external façades could be installed in a position closer to the public street.

In recent decades, Japan has had

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**Table 7.1. Recommended curtain wall performance standards for Japan.**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Wind Load (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calculated by Ministry of Construction Public Notice No. 1458 The return period is 50 years.</td>
</tr>
<tr>
<td>2</td>
<td>Calculated by Ministry of Construction Public Notice No. 1458 With standard wind speed multiplied by correction coefficient 1.07 that is estimated for return period 100 years</td>
</tr>
<tr>
<td>3</td>
<td>Calculated by Ministry of Construction Public Notice No. 1458 With standard wind speed multiplied by correction coefficient 1.19 that is estimated for return period 300 years</td>
</tr>
</tbody>
</table>

**Table 7.2. Recommended wind pressure resistance levels for building heights up to 60 meters.**

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Pressure (N/m², Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 1</td>
</tr>
<tr>
<td></td>
<td>Positive (+)</td>
</tr>
<tr>
<td>13</td>
<td>1,659</td>
</tr>
<tr>
<td>20</td>
<td>1,879</td>
</tr>
<tr>
<td>30</td>
<td>2,055</td>
</tr>
<tr>
<td>40</td>
<td>2,132</td>
</tr>
<tr>
<td>50</td>
<td>2,331</td>
</tr>
<tr>
<td>60</td>
<td>2,507</td>
</tr>
</tbody>
</table>

Source: Ministry of Construction Public Notice No. 1458
8.1 Principal Design Rules

The façade design rules in the Philippines are fundamentally dictated by the National Building Code of the Philippines (NBCP) and by the National Structural Code of the Philippines (NSCP). Imposed design loads, dead and live, are detailed in the structural engineer’s design criteria and are found in National Structural Code of the Philippines (NSCP) 2015 – Volume I, Building, Towers, and Other Vertical Structures. This code is based on US ASCE 7 and identifies the parameters for building protection of façades when located in windborne debris regions within the Philippines. The windborne debris regions are described as areas located within 1.6 kilometers of the coastal mean high-water line (with a wind speed equal to, or greater than 58 m/s), or areas where the basic wind speed is equal to or greater than 63 m/s. When the glazing systems are located more than 18 meters above the ground, and 9 meters above aggregate-surfaced roofs (including roofs with gravel or stone ballasts) within 450 meters from the coastline, the system shall be considered unprotected. The windborne debris regions are identified depending on the occupancy category of the building (see Table 8.1 and Figure 8.1).

In the Philippines, the NSCP indicates that the ASTM E1886 and ASTM E1996 tests should be conducted in order to verify the effectiveness of the window components in protecting against flying debris for the following building categories and locations:

From the National Structural Code of the Philippines 2015:

§207A.10.3 Protection of Glazed Openings
Glazed openings in Occupancy Category I, II, III or IV building located in tropical cyclone-prone regions shall be protected as specified in this Section.

§207A.10.3.1 Windborne Debris Regions
Glazed openings shall be protected in accordance with Section §207A.10.3.2 in the following locations:

1. Within 1.6 km of the coastal mean high water line where the basic wind speed is equal to or greater than 58 m/s, or
2. In areas where the basic wind speed is equal to or greater than 63 m/s.

For occupancy category III and IV buildings and structures, except health care facilities and occupancy category II buildings and structures, the windborne debris region shall be based on Figure 8.1. Occupancy category shall be determined in accordance with Section 103.

Exceptions:
Glazing located over 18 m above the ground and over 9 m above aggregate-surfaced-roofs, including roof with gravel or stone ballast, located within 450 m of the building shall be permitted to be unprotected.

8.2 Professional Roles and Responsibilities

Developers
The Philippines are experiencing a considerable boom in the construction sector. There are zones that used to be shanty towns, which have been converted into clusters of skyscrapers with huge shopping malls in their basement floors. This massive demand for more commercial and residential space to sell and rent has seen many of these buildings being constructed in the past few years. In certain cases, the spaces were sold before construction was completed, and this has had an effect on the quality and performance of the curtain walls that have been installed. In several cases, the developers adhered to only the minimum standards required by the contracts and the local laws, in order to save money and increase profits.

No certification or test reports are mandatory to present to the government institutions in the Philippines. As a consequence, the decision to adopt a curtain wall is

<table>
<thead>
<tr>
<th>Occupancy Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Essential</td>
</tr>
<tr>
<td>II</td>
<td>Hazardous</td>
</tr>
<tr>
<td>III</td>
<td>Special Occupancy</td>
</tr>
<tr>
<td>IV</td>
<td>Standard Occupancy</td>
</tr>
<tr>
<td>V</td>
<td>Miscellaneous</td>
</tr>
</tbody>
</table>

dictated by cost and façade design, which negatively affects quality and performance. Furthermore, insurance companies are not pushing to upgrade the performance of the building envelope, even though the buildings are in typhoon-prone locations. The developers’ priority regarding the façade is simply to protect it from negative consequences that are not covered by the façade suppliers’ guarantees. In this way, if damage occurs, the suppliers have to provide assistance and repair or replace the façade components, instead of holding the developer liable.

Sometimes, the developer will demand higher-performance curtain walls in order to add value to the property and to stand out from adjacent properties. The approach to apply for a certification process for the curtain wall is generally to achieve a specific level of performance normally related with energy savings. This practice has become more common in recent years, and could generate further value when the property has to be sold or rented; if the developers and owners request a certification, the building components will certainly increase the property value. In most cases, developers have the final say regarding cost, and are not inclined to go beyond statutory requirements.

**Designers**

Local architects lack expertise regarding safety performance of curtain walls, beyond the understanding that laminated glass solutions generally

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**Figure 8.1. Basic wind speeds for occupancy category III, IV, V buildings and other structures. © Source: National Structural Code of the Philippines 2015.**
This research highlighted specific aspects related to cyclone-prone façades, as relates to façade technology development and best practices, code requirements, the Asia-Pacific market, and to design approaches.

9.1 Research Summary

Data on past cyclone events, and on local populations and economies, are briefly presented in the first sections of this publication. These, together with a GIS analysis on past cyclone events and on tall building locations, show the existing threats to cyclone-prone structures in the Asia-Pacific region.

The link between curtain walls and high-rises is deep and, if the application of cyclone-resistant façade systems is appropriate, they could serve as refuges for building occupants (Judah & Cousins 2015), instead of remaining as urban features that need to be evacuated or risk damage. Correlating the GIS analysis to this building typology that is concentrated in cities and megacities, this study’s findings present tangible evidence. As of the conclusion of this study in December 2017, more than half of the tall buildings set in the 12 analyzed Asia-Pacific jurisdictions are located in cyclone-prone areas.

Facade engineering in the past few decades has continued to undergo innovations. Among other things, performance upgrades have reduced the vulnerability of occupants and property to natural disasters, and among the others to cyclones/hurricanes. In Miami-Dade County, Florida, through the effectiveness of the applied standards, curtain wall systems have proven to be cyclone-resistant (Miami-Dade County Building Code Compliance Office 2006). However, it took a major disaster (Hurricane Andrew, 1992) before Florida developed local building codes to prevent damage caused by violent storms (ICC 2014a), even though Australia had undergone a similar disaster and implemented comparable measures almost 20 years prior, with Cyclone Tracy (1974) being followed by the Australian Technical Record 440 (EBS 1978). The requirement for these façades is to withstand impacts that simulate flying debris during strong storms.

Even if most of the projects have a tailor-made solution for their glazed envelopes, and the various solutions change from one to the other, the main characteristics of the façades that have already sustained real-life storm conditions have been presented. The “certified” cyclone-resistant façades must be tested in order to verify specific performance criteria that have been identified as representative of the natural phenomena.

Since the 1970s, the primary cause of building envelope damage during strong wind events has been identified as the impact of flying debris (ASCE 2018). Moreover, during a cyclone event, there are big pressure differentials between the windward and the leeward faces of the building. Therefore, the existing current worldwide testing procedures for cyclone-resistant façades aim to verify two main performance objectives. The first performance criterion is resistance to the impact of flying objects (missile-impact testing). Australia, Bangladesh, Japan, and the Philippines are Asia-Pacific countries where this requirement is settled in the local regulation for cyclone-prone areas. The second performance criterion is the impacted glass withstanding 9,000 cycles of positive and negative pressure (ASEP 2015, HBRI 2014, ICC 2016, JSA 2018). This second step of the testing procedure is still not required across Australia: only Queensland’s public cyclone shelters have to perform a wind-load test after the impact test, and even this is only for roofs of buildings and for cyclone-debris screens (Queensland Government 2006).

The research emphasized how, in the Asia-Pacific region, the world’s most-prone area to wind-related natural disasters (World Bank Group 2016b), there is still a lack of requirements for certified cyclone-resistant façades. Furthermore, it presents the best practices of four Asia-Pacific jurisdictions, and the building case studies show how the design approaches of the local professionals consider the cyclone-prone location of these constructions.

In Australia, in Japan, and in the Philippines, there are requirements for cyclone-resistant glazing, but in Hong Kong there is still no prescription:
Australia

Australia has a debris-impact loading standard for building façades (AS/NZS 1170.2: 2011), but still has no test standard for debris-impact-resistant glass. According to the Australasian Wind Engineering Society, the façade industry is working on a standard which it hopes to finalize in 2019 (AWES 2018). Furthermore, no pressure cycling is required for a façade that has already been impact-tested, contrasting with the US and international standards, where the test is an essential component. Cyclic pressure-testing of elements of buildings was addressed in the TR440 report, on which US codes were based, but never adopted in Australia, apart from roofs of buildings and cyclone-debris screens on cyclone shelters (Queensland Government 2006; ABCB 2016). This remained the case, even as subsequent testing in the United States following Hurricane Andrew in 1992 validated the application of cyclic pressure testing to cyclone/hurricane-resistant glazing.

Hong Kong

Hong Kong’s Buildings Department published in 2018 the Code of Practice for Structural Use of Glass, which does not include requirements for flying-debris resistance of glass during typhoon events. In 2018, buildings in this region experienced severe façade damage (especially during Typhoon Mangkhut) due to windborne debris. There are countless objects in the urban environment that could become debris and impact curtain walls in strong wind events. In the future, curtain walls (defined as glass panes with a surface area greater than 2.5 square meters) will be required to have a laminated glass solution in portions of the building with a height higher than 5 meters. This requirement, however, doesn’t aim to prevent the possible glass failure of façades installed at the ground level (lower than 5 meters) that usually host public commercial spaces, especially in Hong Kong’s tall buildings.

Japan

Japan introduced the test standard method for “windstorm-resistant glazing” in JIS R 3109:2018. The buildings in typhoon-prone areas now should use windstorm-resistant certified glass. The standard procedure, however, doesn’t require the entire system to be tested; instead, it requires only a standard measure of a glass pane in a standard frame. The impact locations are clearly identified in the standard, and subsequent pressure cycling must be conducted on the impacted glass specimen.

The Philippines

The Philippines have requirements for typhoon-resistant façades (ASEP 2015), but there is no control by the local authorities over the implementation of the instituted rules. From the 2010 edition of the National Structural Code of the Philippines (ASEP 2010), the façades in typhoon-prone areas must be tested according to ASTM E1886 and ASTM E1996, but currently no testing reports are required to be

“In Australia, no pressure cycling is required to permit a façade that has already been impact-tested, contrasting with international standards, where the test is an essential component.”
Over the past decade, the Asia-Pacific region has seen unprecedented growth in terms of its economy and its urban population. As growth in this area occurs, the demand for additional high-density residential and office space has also increased, resulting in record numbers of high-rise buildings being constructed, concentrated primarily in urban areas. The urban growth in this region has largely occurred in coastal areas, which unfortunately are becoming increasingly vulnerable to cyclones and typhoons. This research report presents the norms and standards of the major tall building markets in 12 jurisdictions within the Asia-Pacific region (including Australia and New Zealand), for the impact of flying debris on curtain walls during strong wind events in the urban environment. It provides a critical and urgent summary of the gap between the level of risk and the level of regulation concerning façade resilience in these vulnerable, highly populated regions. This report will serve as an indispensable reference document for industries and professionals in the design and renovation of curtain walls, and as a means of presenting tangible examples of the existing best practices in the Asia-Pacific region to developers and building owners.