Hurricane Resistant Curtain Wall System

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Abstract *— Puerto Rico is in the storm and hurricane trajectory zone. For the past years we have seen an increase in the quantity and intensity of these atmospheric phenomena due to climate changes. On September 20, 2017 Hurricane Maria impacted Puerto Rico, and was considered the worst natural disaster on record for the past 80 years. This system left catastrophic damage and human impact on the island. The National Weather Service considered it the tenth most intense Atlantic Hurricane on record and the most intense tropical cyclone worldwide. This project intends to create awareness regarding Puerto Rico's vulnerability when faced with Mother Nature's fury and how to incorporate a resilient design in future structures. The main purpose of this research is to provide a secure alternative to those who want to incorporate storefront and glazed assemblies on buildings located in vulnerable areas where the hurricane forces are more intense.*

Key Terms — *Awareness, Hurricane Resistant Curtain Wall System, Hurricane Threats, Resilient Structural Design & Construction.*

INTRODUCTION

This report emphasizes the immense propensity Puerto Rico has to experience hurricane threats due to its geographic location and climate changes, and the necessity of building construction soundness to survive stronger natural disaster. This concept is known as resilient building design and construction. Resilient construction takes into consideration not what has happened before, like Hurricane Hugo and George, it goes beyond what happened with Hurricane Maria. After experiencing Hurricane George, Puerto Rico follows the 2011 International Building Code, which requires buildings to withstand 140 mph winds, characteristic of a Category 3 storm.

Most of the hurricanes originated in the Atlantic Ocean are formed when the sun warms the tropical waters from the Cape Verde Islands in the west of Africa to at least 80°F. Warm humid air moves towards the African coast causing these diverse forces to organize and progressively increase intensity. Puerto Rico is in the pathway of all Atlantic Ocean threats.

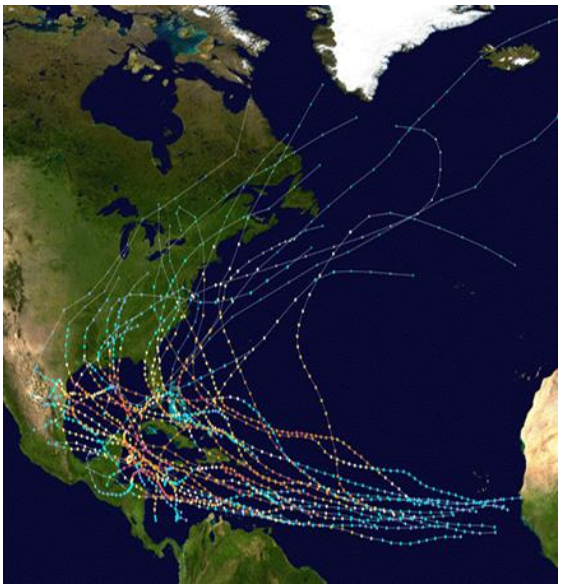

Figure 1
Trajectory of Atlantic Atmospheric Phenomenon

The construction team of engineers, architect and building contractors needs to keep in mind the possibility of an intensification in the earth's atmosphere threats. It is necessary to design and build stronger structures while maintaining an effective cost for future projects. The incorporation of a hurricane resistant curtain wall system is an extremely secure alternative to use without sacrificing the aesthetics and beauty of glazed assemblies in buildings and structures. This system

can be used for residential, commercial, and industrial constructions.

OBJECTIVES

The main purpose of this research project is to demonstrate that the system analyzed is resistant and is a secure alternative to be used in areas exposed to hurricane threats. The hurricane resistant curtain wall that was installed resisted Hurricane Maria's impact demonstrating to be a resilient design and construction.

LITERATURE REVIEW

Hurricane-Resistant Curtain Wall is designed to meet the most demanding performance requirements for areas exposed to hurricane and other severe weather. CR Laurence – U.S. Aluminum, a leading manufacturer and supplier of architectural glazing system for 60 years, has introduced StormWallXL™ Hurricane-Resistant Curtain Wall. The curtain wall is engineered to provide steadfast protection against severe weather while meeting stringent building code requirements. It is NFRC–rated, has Florida Product Approval, Miami-Dade Certified (NOA), and is fully tested to ASTM and TAS Standards. This is an innovative system that meet unique regional requirements, presents a credentialed, impact–resistant glazing solution for coastal communities that completes a comprehensive product offering. The assemblage takes into consideration the site peculiarities, including but not limited to the expansion and contraction movements so there is no possibility of loosening, weakening, or fracturing connection between units and building structure or assembly between units themselves. It provides the best defense against high winds, airborne debris, and water infiltration. Designed and engineered for exceptional strength, reliability, and quality, it ensures that architects and glazing contractors receive the best high-performance curtain wall for their at-risk projects. The system integrates seamlessly with CRL-U.S. hurricane-resistant windows and doors to provide a complete building envelope solution. The system offers shear block assembly with no exposed fasteners for improved aesthetics and installation flexibility [1].

Figure 2
StormWallXL™ System Assembly

METHODOLOGY

This project incorporates as principal methodology a literature review based on a case study of a fitness center constructed in The San Juan Hotel as part of the hotel renovation. This structure is a new three-story building made with concrete foundations, structural steel, and structural purlin. The first and second floor are surrounded with the StormWallXL™ Hurricane-Resistant Curtain Wall, as part of the building envelope. The other areas where made with purlin and cement board covered with an exterior insulation finish system. The third floor is the roof top with an outdoor track and outdoor weights area.

The concrete foundations design required A-2-4 backfill compacted at 95% of maximum density as per ASTM D1557 Modified Proctor. The design is based on 2,500 psf soil bearing value and 150 kcf coefficient of subgrade reactions. Concrete shall be stone concrete utilizing aggregate conforming to ASTM C33 and cement shall be Type I conforming to ASTM C150. Concrete in the main building shall

have a corrosion inhibitor additive due to the structure's location. Concrete strength at 28 days for foundation, elevated slab, and beams was specified to be 4,000 psi with a water/cement ration of 0.50. Ground slab concrete strength at 28 days was specified at 3,500 psi with a water/cement ration of 0.55.

Figure 3
Fitness Center Facility

The structural steel design required all wide flange beams, girders, and base plates to be ASTM A992 material, designed using 50 ksi Yield strength. Columns shall be welded seamless pipe conforming to ASTM A501. Square or rectangular tubes shall be welded seamless sections made of steel conforming to ASTM A500, Grade B. Bolted connections shall consist of unfinished bolts conforming to ASTM 325N [2].

Curtain Wall Structural Steel Support

The Hurricane Resistant Curtain Wall is supported by hot dip galvanized and painted beams and columns, forming the second-floor framing plan, roof framing plan, and side frame elevations.

Table 1
Beams and Columns Size & Shape

Beams	Columns
W10X12	W10X45
W16X26	HSS6X6

The structural design loads were very strict due to the building location. The location of this new facility is in the hotel backyard, in front of the olympic pool and approximately 110 ft from Isla Verde beach.

Figure 4
Fitness Center Location with Ocean Reference

Table 2
Design Load Requirements

Design Criteria	Parameter
Live Load	
• Typical Roof Load	100 PSF
• Second Floor Load	100 PSF
Wind Load Design Parameter	
• Basic Wind Speed	145 MPH
• Wind Load Factor	1
• Wind Exposure	C
Wind Load on Structural Frame	
• Vertical Surface 0 to 15 ft	53 PSF
• Horizontal Surface	66 PSF
Wind Load on Cladding	Pressure Suction
• Vertical Surface	
○ Typical wall	63 PSF -66 PSF
○ Wall Corners and Edges	63 PSF -78 PSF
• Horizontal Surfaces	
○ Typical Roof	37 PSF -67 PSF
○ Roof Edges	37 PSF -101 PSF
• Roof Corners	37 PSF -144 PSF
Lateral Loads	
• Seismic Design Category	D
• Seismic Factor, I	1.00
• Seismic Factor, Ip	1.50
• Site Classification	D
• Spectral Short Periods Ss	0.90g
• Spectral Long Periods S1	0.31g
• Seismic Coefficient, Fa	1.14
• Seismic Coefficient, Fv	1.78

CMA Architect & Engineers LLC was the architect of record and MEPF engineering firm for the fitness center facility. The reference used for live load (second floor and typical roof) and lateral seismic loads was the IBC 2009. For the wind load design parameters on the structural frame and on the cladding, the ASCE 7-05 was used as reference. The size and shape of the structural beams and columns used did not vary much for the slab

framing and for each frame side elevation to support the Curtain Wall [2].

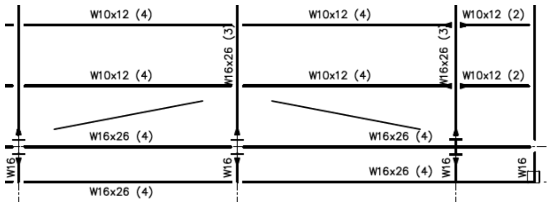

Figure 5

Cut Section Second Floor Framing: South-East

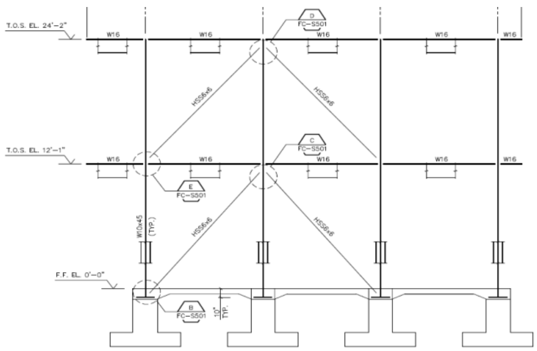

Figure 6

Frame Elevation East Side – Ocean Front

Figure 7

Curtain Wall Installed: South-East View

Validation: Hurricane Maria's Impact

The construction of the fitness center finalized on May 2017 with the grand opening of the remodeled hotel. Four months later, on September 20, Hurricane Maria destroyed almost 80% of the renovated hotel, but the fitness center remained intact. The building envelope not only endured and resisted the hurricane's fury, but also protected all the interior facilities.

Hurricane Maria made landfall in Yabucoa, Puerto Rico as a strong category 4 hurricane with sustained winds of 155 mph [3]. Widespread, hurricane force winds spread all over the mainland along with extremely heavy rainfall that produced major to catastrophic flooding and flash flooding, across the northern half of Puerto Rico [3].

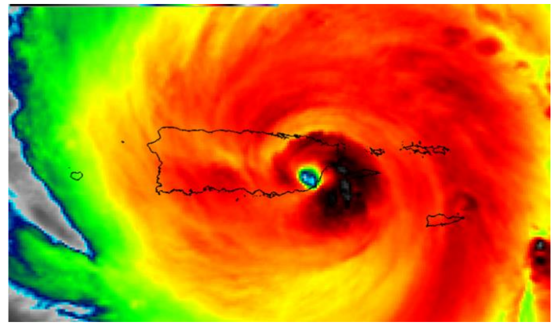

Figure 8

Hurricane Maria Satellite Imagery

Hurricane Maria, on Isla Verde Ave. in Carolina, produced approximately 25 inches of rainfall, sustained winds of 155 mph and maximum wind gusts registered 175 mph up to 190 mph approximately. The maximum storm surge registered in this area was 2.35 ft above mean sea level. The San Juan buoy number 41053 reported on September 20, 2017 a significant wave height of 20 ft. The combined destructive power of storm surge and wave action from Maria produced extensive damage to buildings, homes, and roads along the northeastern coast of Puerto Rico [4]. The phenomenon's extreme force winds produced massive air borne debris impacting and destroying most of the glass assemblies on Isla Verde Avenue. The hurricane center of circulation spent 8 hours over land and, as it emerged into the Atlantic Ocean, Maria continued to bring torrential rainfall to Puerto Rico that prompted extensive flash flooding. Isla Verde Avenue was impassable as well as the Villamar marginal street because they had flooded sections and others that were obstructed by objects such as garbage containers, gates and, cement posts, some submerged in the water [5].

Interview with Hotel Personnel

On March 2019, after the second opening, hotel personnel was interviewed with the purpose of listening from them the experience lived after this devastating and destructive hurricane in their place of work. The names of the employees

interviewed shall not be disclosed and pictures of the devastated hotel shall not be shown, as requested by hotel management. The information obtained can be summarized as follows:

- Exterior areas, including but not limited to pools, bar and restaurant were completely flooded and fully covered with sand. This same situation reached up to the Isla Verde Avenue (approximately 400 ft from the ocean).
- Some of the balcony sliding glass doors of *Las Casitas Villas* were broken into pieces due to flying debris. The villas are located behind the fitness center.
- The fitness center did not have any damages.
- *Cañas'* (ocean front restaurant) glass railing surrrounding its outdoor eating area was completely destroyed.
- Airborne debris broke several of the main building windows, causing flooding in the majority of the hotel rooms.
- The Meeting Rooms were completely flooded with more than 6 ft of water. These offices are inside the building, below ground level.

ANALYSIS AND RESULTS

The San Juan Hotel remained closed a year and a half to complete all the repairs needed due to the damages caused by Hurricane Maria. This hotel was out of business four months after a major renovation investment. The fitness center was part of this renovation and was the only facility that was not affected by the disaster. The reason this building resisted the hurricane's fury was because the StormWallXL Curtain Wall System installed made the structure envelope strong enough to sustain winds beyond the design criteria of 145 mph. The performance obtained from this curtain wall system validated all the specifications and tests results obtained by the manufacturer as explained in the Literature Review section.

Curtain Wall System Specification and Test

The product type Curtain Wall System series/model StormWallXL™ is a single source responsibility that provide an inovating alternative for the building envelope. Design, extrusion, fabrication, and finishing occur at the same facility, and under strict tolerances, assuring uniformity of profile and finishes among systems. All the tests conducted to this system were made by a third party named Architectural Testing, Inc. This company was contracted by CR-L to perform and report all the results obtained to confirm compliance specification with each corresponding ASTM. The following table mentions and describes each ASTM used.

Table 3
ASTM Description

ASTM	Description
ASTM E 283-91	Test method determining rate of inflow through exterior window, curtain walls, and doors under specified pressure differences across the specimen
ASTM E 330 -02	Test method for structural performance of exterior window, curtain walls, and doors by uniform static air pressure difference
ASTM E 331-91	Test method for water penetration of exterior windows, curtain walls, and doors by uniform static air pressure difference
ASTM E 1886-05	Standard test method for performance of curtain walls, doors, and storm shutters impacted by missile (s) and exposed to cyclic pressure differentials
ASTM E 1996-05	Standard specification for performance of exterior windows, glazed curtain walls, doors and storm shutters impacted by wind borne debris in hurricanes
ASTM C 1363-11	Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus

Thermal Specifications and Test

The system is thermally improved using a continuous thermal spacer interlocked within the horizontal and vertical pressure bar. With U-factors as low as 0.38, the system easily satisfies the Florida Building Code Fifth Edition (2014) Energy Conservation requirement. Tested in accordance with ASTM C1363-11 for thermal performance of building materials and envelope assemblies, including but not limited to glass and frame. The frame accommodate expansion and contraction movement due to surface temperature differentials without causing buckling, stress on glass, failure of

joint seals, excessive stress on structural elements, reduction of performance, or other detrimental effects [6].

Air & Water Infiltration Specifications and Test

Air leakage through fixed light areas of storefront is tested in accordance with Florida Building Code Test Protocol (TAS-202) and ASTM E 283-91 at differential static pressure of 6.24 psf. Water infiltration is tested in accordance with ASTM E 331-91 at test pressure of 15 psf and water penetration test pressure is 12 psf with Dade County Protocol TAS 202-94. The system provided internal drainage of infiltrated water into an extruded aluminum subsill channel where it is drained to the exterior through weep slots. The system elements, including windows and frame are weathertight and used Structural Glazed Vertical Mullions to control water infiltration [6].

Cyclic Load Specifications and Test

Cyclic test is a type of test in which a product, material, or object is subjected to repeated testing instead of a single test cycle. The goal of such testing is to confirm that the product will perform reliably and to get an opportunity to subject it to simulations of many different real-world conditions. This provides a more accurate idea of how the product will perform in the real world, as most products are used for an extended period of time. A cyclic test can demonstrate the capacity of a new product and its performance over time, including fatigue failures. These test methods also intend to measure the performance of vertical elements of lateral force similar to earthquake loads. It cover the evaluation of wind loads and ductility of vertical elements submitted to lateral force [6].

Additional Hurricane Resistance Specifications

This durable curtain wall is tested under the most rigorous and severe conditions to obtain and validate the manufacturer's specifications for each element that is part of the hurricane resistant curtain wall system. These specifications include but are not limited to missile impact (large missile), design pressure, and high wind loads. The missile impact test takes into consideration some of the possible windborne debris caused by the hurricane extreme wind, calculated in miles per hours [6].

Table 4
Resistant Specifications

Characteristic	Parameter
Missile Impact	Level D: 9 lb lumber at 33.55 mph
Design Pressure	Up to +100/-100 PSF
High Winds	Wind Zone No. 3 & 4

CONCLUSIONS

The subject of this study, the StormWallXL™, is a high-performance hurricane resistant storefront designed for all commercial entrance applications including retail space, hotels, condominiums, office buildings, institutional facilities, and industrial structures. This Storm Curtain Wall System resisted sustained winds of 155 mph, with wind gusts of up to 190 mph in front of a cyclonic storm surge. This achievement brings to mind the resilient building design concept. Resilient design is the intentional design of buildings, landscapes, communities, and regions in response to vulnerabilities to disaster and disruption of normal life. In the case of Puerto Rico, that has a wet climate and implications for plate tectonics due to geographical location, resilient constructions need to plan to overcome natural disaster including hurricanes, flooding, and seismic activities. The product tested in this research, StormWallXL™, complies with the resilient concept for extreme weather areas. It was able to resist severe wind loads, heavy precipitation, and ground level flooding. The Hurricane Resistant Curtain Wall System provided a very well-sealed envelope to the building and adequate drainage solutions to the structure.

Preserving the building envelope is the most important characteristic in the construction design. Selecting the correct materials is essential to maintain the integrity of the structure, ensuring non-destructive impacts from wind flow shall occur during hurricane season. With the high-speed winds

of a hurricane, objects can be lifted and become an airborne missile or wind-borne debris. When wind-borne debris breaks glass windows or doors, the building's protective exterior is compromised, potentially allowing strong winds to rush into the structure. These trapped wind forces will increase pressure on the roof and outward pressure on exterior walls, and can eventually cause total destruction. The Hurricane Resistant Curtain Wall studied in this project guarantees this will not happen, even after years of installation. All the tests made and the results obtained with this system confirm this statement. In addition, the StormWallXL has a cold-applied asphalt mastic as a protective coating complying with the Society for Protective Coatings SSPC-Paint for above ground steel structures. This system is suitable to be used on parts or structures exposed in Environmental Zones 2A (frequently wet by fresh water), 2B (frequently wet by salt water), 3B (chemical, neutral), and 3C (chemical, alkaline).

The experience lived during such a catastrophic event as Hurricane Maria in the island inspired this project. Seeing how this powerful system damaged so many structures, affected human lives, and local economy shows us the importance of taking into account our geographical location, environment, and natural threats when designing structures in order to protect them beforehand from harm. In Puerto Rico, the resilient building design concept should be applied to all structures.

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