Literature Review

A new design for residential roofs resistant to hurricane-force winds

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Table of contents

Introduction

Hurricanes are major natural disasters that can cause damage to buildings. These storms produce high winds, heavy rain, and low pressure that can severely damage most infrastructure. Some other attributes of hurricanes that might pose as threats are storm surges, which are similar to floods, sea level rises, and mudslides (“Hurricane Damage”, 2011). Hurricanes are strongest over water, but as it moves inland to where more people live, they become weaker (“Hurricane Damage”, 2011). Some attributes of the storm, such as beach erosion and storm surges, are no longer relevant for inland areas because there is no ocean nor sea nearby to pose as threats. In terms of costs, hurricanes are extremely damaging. The government costs of hurricane damage each year are on average $28 billion dollars (Amadeo, 2019). This will likely increase due to climate change, as hurricanes become more severe, with cost estimates reaching $39 billion by 2075 (Amadeo, 2019). The increase in severity comes from ocean waters warming, which feeds energy into the hurricane. Another consequence of climate change would be the decrease of lateral speed in hurricanes. In 2018, a study was conducted and it found that hurricanes have slowed down by 10% since 1949 (Amadeo, 2019). This allows hurricanes to stay in one place for longer, and thus creating more damage. The government pays for 60% of the damages from hurricanes, and the rest being paid by the state, insurance, and private landowners (Amadeo, 2019). There are other losses to consider other than cost. Major hurricanes can kill hundreds or thousands of people, some examples being hurricane Katrina causing the deaths of 1,836 people and hurricane Maria killing 2,975 people (Amadeo,

2019). With these damages, a number or organizations have been founded to raise money to create buildings that are more resistant to natural-disasters. However, a New York Times analysis found that many buildings were built similarly to their previously destroyed counterparts, making them equally vulnerable to the next hurricane (Amadeo, 2019). It is becoming ever more urgent that solutions must be found for protecting against hurricanes. The focus of this project is on improving building design, specifically residential roof designs, to minimize the damage from hurricanes.

Definition of a Hurricane

Natural disasters are severe types of weather that are considered threats to human society, health, and infrastructure (“Natural Disasters”, 2018). One of these disasters to focus on is hurricanes which are large storms that produce strong winds and heavy rain (“Natural Disasters”, 2018). Storms are deemed hurricanes based on their wind speed and not their rain; they reach hurricane status when they have sustained wind speeds of over 74 miles per hour (“What is a hurricane?”, 2018). Storms under 74 miles per hour are considered tropical storms or tropical depressions. They can be categorized on the Saffir-Simpson Hurricane Wind Scale from one to five, with higher categories signifying higher wind speeds (Gibbs, 2001). Higher wind speeds cause higher storm surges, greater damage, and power outages. This can be seen in a chart in Figure 1.

Category	Wind Speed	Surge in Feed	Damage	Home Damage	Tree Damage	Power Outages
1	74-95 mph	4-5	Some	Some	Branches	Days
2	96-110 mph	6-8	Extensive	Major	Snapped	Weeks
3	111-129 mph	9-12	Devastating	Major	Snapped	Weeks
4	130-156 mph	13-18	Catastrophic	Severe	Toppled	Months
5	157+ mph	19+	Catastrophic	Destroyed	Toppled	Months

Figure 1. Amadeo, K. (2019). A chart with what wind speeds, amount of damage, and types of damage for different categories of hurricanes. Retrieved from https://www.thebalance.com/hurricane-damage-economic-costs-4150369

Hurricanes can be categorized into four parts: the boundary layer, the region above the boundary layer, an updraft region, and the eye (Snaiki, 2018). The eye is where all the winds of the hurricane revolve around, and it contains generally lower wind speeds (Snaiki, 2018). The boundary layer is the area right outside of the eye, and it contains the strongest winds of a hurricane (Snaiki, 2018). This is the area most often focused on when studying the effects of a hurricane because the heavier winds and rain do more damage to structures. The outer parts of a hurricane are much weaker in terms of wind speed, so they are not focused on as much.

Components of Buildings

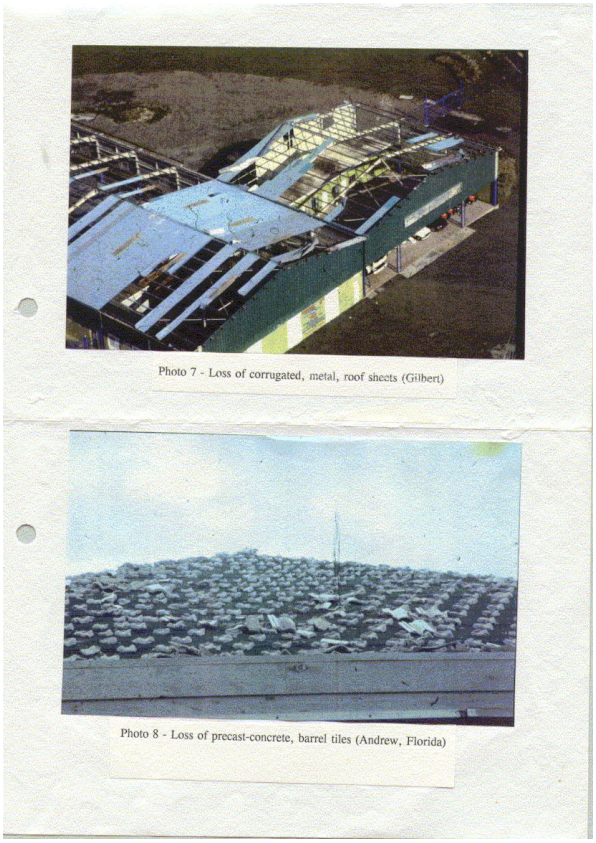
Buildings are made up of many different components. Some examples of components are the foundation, the framing of the building, and the roof. The foundation is at the bottom of the structure and supports the entire weight of the building (“Foundation types and uses”, 2018). Shallow foundations can be categorized into two types. The first type is footings, which extend only one to three meters into the ground, and the second type is mat foundations, which is a single slab of concrete on which the building rests. (“Foundation types and uses”, 2018). These types of foundations are used for smaller buildings. Deeper foundations can be concrete-steel piles that are driven into the ground, which support much larger buildings such as skyscrapers (“Foundation types and uses”, 2018). The material making up foundations can be made up of stone, earth, concrete, or brick (“All Types of Foundation Materials”, n.d.). Because the foundation is in direct contact with the ground, it is often shielded from the wind, and would only be a problem if the building was lifted off of the ground. A more vulnerable component of a building would be the roofs. Roofs are a component that is on top of a building. Most residential roofs are made out of a wooden frame, with asphalt shingles on top (What Makes Up a Roof, 2018). A roof itself has many different components, including purlins, rafters, gables, corners, end bays, and eaves. Purlins and rafters are part of the main framing of the roof. They are normally made out of thick pieces of wood, often 2x4, 2x6, or 2x8 inches (What Makes Up a Roof, 2018). They support the weight of the roof. Gables are the exterior walls underneath the overhangs of the roof. They are triangles, and the walls often merge with them as the wall extends into the wedge of the roof. Corners, end bays, and eaves are different parts of the

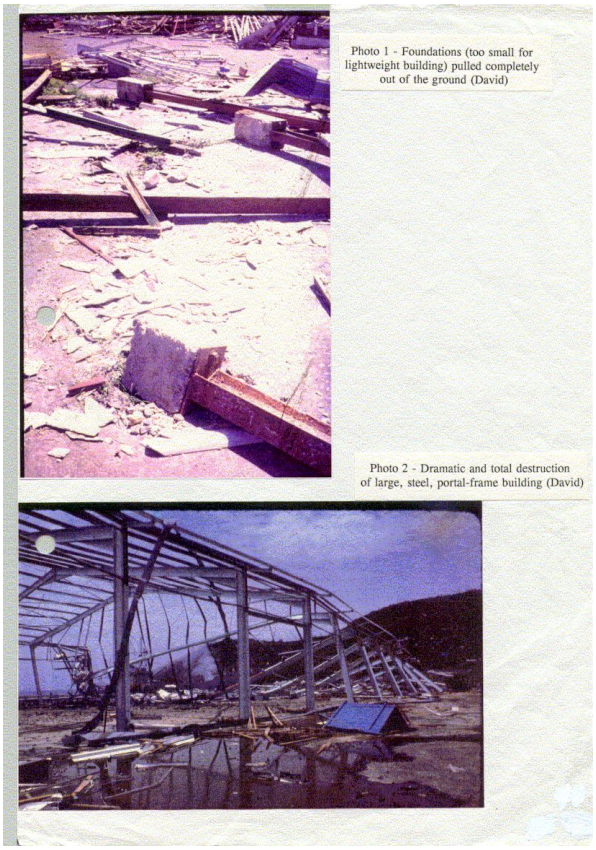
overhangs of a roof. They often have ventilation which gives fresher air to the attic (What Makes Up a Roof, 2018). More details about roofs will be in later sections.

The Effect of Hurricanes on Buildings

Of the many types of natural disasters, hurricanes are one of the most costly in terms of damages. Seven out of the top ten most costly natural disasters are hurricanes (He, 2017). Some examples of hurricanes are hurricane Hugo causing eight billion dollars in property damages in 1989 and hurricane Andrew causing thirty billion dollars in damages in 1992 (Gibbs, 2001). Major structural faults are more severe, and often result in partial or total building collapse, but component faults happen much more frequently. If a foundation is not sturdy enough, it can be lifted off the ground. This can also happen in the framing where connections break and steel beams disconnect (Gibbs, 2001). Both of these are structural faults and can be seen in Figure 2. Some examples of component faults are in the roofs, where weaknesses are in fasteners and the thinness of sheets, windows, and walls (Gibbs, 2001). These can be seen in Figure 3. The roofs are the most common component to fail during a hurricane (Gibbs, 2001). The location of a building plays a factor in determining its resistance against hurricanes. Buildings that are on hills or in valleys are exposed to higher wind speeds than those just on plains (Gibbs, 2001). On hills, winds are not disrupted by terrain or trees, meaning it has more time to accelerate. In valleys, winds can sweep down the sides, and when the winds of one side of the valley reach the other, the two combine and produce stronger winds. The shape of buildings also affects how much damage they receive. Buildings that are symmetrical and square are more resistant to hurricanes

than buildings that are asymmetrical and unstructured (Gibbs, 2001). For the roofs, designs that are steeper and have little overhangs are best, since that design makes it less likely for winds to curl under the tiles and pick them off (Gibbs, 2001).





(Right) Figure 2. Gibbs, T. (2001). Destruction of a foundation and steel framing. Retrieved from https://www.oas.org/pgdm/document/BITC/papers/gibbs/gibb0102.gif

(Left) Figure 3. Gibbs, T. (2001). Destruction of roofing. Retrieved from https://www.oas.org/pgdm/document/BITC/papers/gibbs/gibb0105.gif

Specifics of roofs

Roofs are structural elements that are on the top of buildings. The main frame of the roof is made of rafters, purlins, trusses, and joists (What Makes Up a Roof, 2018). The rest of the roof is built on this frame. Normally, the frame is made out of wood, and

the most common type of wood for the frame is plywood (What Makes Up a Roof, 2018). However, depending on the location and building codes, some areas may require stronger woods instead, such as fir, pine, or spruce (Building Code for Roof Rafters, n.d.). Rafters and purlins are main parts of the frame, with rafters going vertically up the roof and purlins going horizontally across the roof. Rafters are typically spaced a minimum of 16, 19.2, or 24 inches apart, with their dimensions being 2x4, 2x6, or 2x8 inches (Building Code for Roof Rafters, n.d.). Another part of the roof are the eaves and the end bays. These are parts of a roof that hang off the side of a building. The next part of a roof is the underlayment. It is a barrier made of asphalt-saturated felt and is attached directly to the frame (What Makes Up a Roof, 2018). It is beneath the shingles and supports it. In addition, it also acts as a water barrier incase rain seeps through the shingles (What Makes Up a Roof, 2018). The shingles themselves are the most visible part of the roof and are the most common roof covering in North America (What Makes Up a Roof, 2018). 3-tab shingles are cheap and are the same size and shape, meaning they look uniform on a roof, while architectural shingles are different sizes and shapes (What Makes Up a Roof, 2018). Both types of shingles used to be made of wood and slate, but more recently, asphalt became the standard material (What Makes Up a Roof, 2018). Another component of a roof is the soffit. When a roof overhangs a wall, it creates an eave. The soffit covers up the space, and usually has holes in it for ventilation (What Makes Up a Roof, 2018).

Hurricane's effect on roofs

Out of the many components of buildings, hurricanes affect roofs the most. A model was created in 2012 to measure the effects of a hurricane on different aspects of buildings to see how much damage there was compared to wind speeds. The study conducted by Pita et al. (2012) looked at roof covers, gables, walls, windows, and doors. Under 40 meters per second, around 90 miles per hour, there was minimal damage to any of these parts, but at 70 meters per second, around 156 miles per hour, nearly 85% of the roof cover was damaged (Pita, 2012). The next most damaged component at 70 miles per hour had less than 50% damage. Roofs are far more susceptible to damage from hurricanes, most likely because they are the most exposed in the air and have the least support. Another study conducted by Stewart et al. (2016) looked at the types of damages to roofs in high wind areas on metal industrial buildings. The researchers found that when the wind was parallel to the direction of the purlins, the main failure was in the corners and end bays, and when the wind was perpendicular to the direction of the purlins, the main failure was in the eaves. Corners, end bays, and eaves are parts of a roof that overhang off the main building. They fail because they are areas of high uplift; wind gets underneath the roof and lifts it up (Stewart, 2016).

Conclusion

Hurricanes are large storms that have heavy rain and strong winds. Billions of dollars in property damage occur every year and the damage is set to increase due to climate change. Hurricanes can cause major damage to multiple components inside a building. Components such as the foundation are well designed and its underground location makes it much more protected against the strong winds of a hurricane. Other

components, such as a roof, are much more vulnerable to winds since they are more exposed. Roofs themselves can be subdivided into several different components, including rafters, purlins, and eaves. The primary cause of a roof failure is the result of the eaves and overhangs. Wind can get underneath a roof and increase air pressure in the eaves. When there is enough pressure, the entire roof can be lifted off, allowing catastrophic damage to the interior of the building. The larger the eaves and overhangs, the larger the risk of roof damage in high winds. This project will focus on minimizing the negatives attributes of overhangs in order to create a roof that is better suited to handle hurricane-force winds.

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