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Disaster Mitigation and Recovery: A Study of Hurricane Hugo's Effect on South Carolina

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Disaster Mitigation and Recovery: A Study of Hurricane Hugo's Effect on South Carolina

by

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Abstract

Disaster Mitigation and Recovery: A Study of Hurricane Hugo's Effect on South Carolina

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Death, destruction, and loss are what many people experience when they encounter a disaster such as a hurricane. One key fact to remember about disasters is that they are a human made event. This is because disasters only occur when a natural hazard comes into contact with human made items. One such natural hazard, hurricanes, can result in significant destruction and have a major impact on humankind.

While humankind is effected by natural hazards, it can also have an effect on the results from these hazards. Using proper techniques, damage from disasters can be reduced by significant portions. This can be accomplished through mitigation, resilience and recovery. The combination of these three components can both reduce and eliminate destruction from disasters caused by natural hazards.

This paper will look at each of these three components and how they apply to disasters caused by hurricanes. The focus will be looking at how differing building requirements can have an effect on the amount of damage caused by hurricanes. These results will then be used to recommend what types of building codes should be used and the political viability of using such codes.

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INTRODUCTION

Death, destruction, and loss are what many people experience when they encounter a disaster such as a hurricane. Houses can be swept way, along with the belongings and people inside. One might consider why nature chose to smite them, but the true blame lies not with nature but with humankind. Disasters are a human made event as they only occur when a natural hazard, such as an earthquake, flood, or hurricane come into contact with human made items. Consider this, does the average person even worry about hurricanes that are born and die on the ocean without ever coming into contact with human made objects?

The effects of hurricane disasters are profound and can result in destruction to human made objects and to the individuals in the impacted area. This destruction comes in multiple forms including loss of life, economic loss, emotional strain, and infrastructure loss. However, these losses are not a certainty and humans can have an enormous effect on the results. It is these human effects that is the focus of this research study. Specifically, which components of building designs produce community and economic benefits.

The disaster process can be viewed in many aspects. One such way to view the process is to consider the design of a stool (an example of which can be seen in the figure below). The seat of the stool is the successful disaster process. The seat is supported by three legs which are mitigation, resilience, and recovery. A sturdy stool requires all three legs to be present. If any of the legs are missing, then the entire stool falls over. The same can be said for the disaster process. To be successful, all three components of the disaster process must be used effectively. If any one of them are not used, then the success of the process is diminished.

Figure 1: Successful Disaster Process Stool

The ability for humans to effect the outcome of a disaster starts well before a hurricane hits. This comes in the form of reducing the vulnerability to an area. The less vulnerable an area is to a hurricane, the easier any recovery will be. This is a concept known as mitigation, and combined with resilience and recovery, make up the basis for dealing with disasters such as hurricanes.

Disaster mitigation has two main components which are soft and hard mitigation (Paterson, 2014). Hard mitigation deals with strengthening structures to withstand the brunt force of hurricanes. This includes the ability to strengthen buildings and infrastructure for new construction and to retrofit existing buildings and infrastructure. Hardening through building codes can help to prevent damage from both wind, water, and debris that are hallmarks of hurricanes.

Soft mitigation deals with non-structural actions that reduce potential damage. This includes zoning, land use, riparian zones, wet land protection, barrier island protection, and regulations. Proper zoning can be used to locate infrastructure, buildings, and services in areas where they are less likely to be impacted by a hurricane. Decisions on land use around areas such as rivers and streams can result in either having infrastructure damaged or placed in a manner that results in little to no damage during a disaster.

Resilience is viewed as the ability to absorb or to withstand the effects of a disaster. It can also be viewed as the ability for a system, community, or person to bounce back from a disaster. This term is derived from multiple studies including studies by Paula Aldunce and Richard Klein. It is explored further in the literature review section below (Aldunce et al.; Klein, Nicholls, and Thomalla, 2015). Resilience can be achieved through proper mitigation and effective long term planning.

Recovery after a disaster can mean the difference between life and death. It can be a deciding factor in who receives help and how quickly that help arrives. It includes items such as evacuation, resupply, and utility repair. Recovery can also be a method to better prepare an area for future disasters, if it is approached in the proper way.

Hazards that result in disasters account for a significant portion of loss as a proportion of a nation's Gross Domestic Product, commonly referred to as GDP. In fact, "…annual economic losses from disasters are estimated…at between US$ 250 billion and US$ 300 billion…" (UNISDR). This is a significant amount of economic loss which has a rippling effect on the global economy.

Hurricane disasters are not a problem that will dissipate. In fact, it is highly likely that these types of disasters will continue to grow in the future. This growth is caused by a couple of contributing factors which are the continued buildout of society in coastal areas and climate change. A recent study from the United Nations Office for Disaster Risk Reduction highlights this when it states, "Over the last twenty years, the overwhelming majority (90%) of disasters have been caused by…weather-related events" (UNISDR). This requires a focus on weather related disasters when it applies to disaster mitigation, resilience, and recovery.

Hurricanes are one of the most dangerous disasters that society faces even though they are not as frequent as other disasters. According to UNISDR, "[w]hile less frequent than flooding, storms were the most deadly type of weather-related disaster…40% of the global total for all weather-related disasters" (UNISDR). With nearly half of all disasters caused by storms, this area of disaster mitigation could produce the largest beneficial results.

The issue of weather related disasters is exasperated due to climate change having an effect on a multitude of disasters. Hurricanes are one such disaster that are effected with climate change. Hurricanes are driven by warm water temperature. As the oceans heat up due to the warming of the planet, the strength and frequency of hurricanes will likely increase. This creates an increased threat to both life and property.

Disasters affect society in both the local area, as well as in the state and country as a whole. Economic loss in a city or town can be felt all the way up to the state and federal level. For example, the loss of economic activity in a city reduces the income to the state via items such as the sales tax. This economic loss continues up the chain to the regional and federal level.

A disaster's effect on a society as a whole is staggering. For instance, "In total, 6,457 weather-related disasters were recorded worldwide…claimed 606,000 lives…with an additional 4.1 billion people injured, left homeless or in need of emergency assistance" (UNISDR). These numbers point to the need for a focus on mitigation efforts to reduce the negative results from disasters such as hurricanes.

This focus should also come from planners. A hazard has the potential to ruin even the best laid plans and designs that a planner can come up with. Planners are essential for the disaster mitigation and recovery effort. They play a role from designing the city in a manner that provides resilience from disasters to planning a recovery process after a disaster. Planning effectively for both disaster mitigation and disaster recovery is essential for a locations success against such events. The need for planners is highlighted in, Adaptive Planning for Disaster Recovery and Resiliency: An Evaluation of 87 Local Recovery Plans in Eight States, by Philip Berke. This article studies disaster recovery at the local level with a focus on the need for appropriate planning (Berke et al., 2015).

RESEARCH QUESTION

The research question for this study deals with the mitigation and resilience legs of the stool described in the introduction. The HAZUS program, designed by the Federal Emergency Management Agency (FEMA), was used to model the disaster and the resulting effects. An in-depth discussion of this program is contained in the research design and methodology section below. One important factor to note is that this research study did not look at storm surge as part of the damage estimates. The specific research question for this study is:

> Changes in buildings codes in areas such as water resistance, shutters, roof types, and connections between the roof and wall will reduced the damage to buildings and the economic loss experienced due to a hurricane.

While building engineering and design can provide information on how structures should respond to external forces, this study will test these design elements to determine their effectiveness for this case study. Successful design components can mitigate damage from a hurricane. This, in turn, provides an aspect of resilience to the area against such disasters in the future.

LITERATURE REVIEW

The knowledge base for disaster mitigation and recovery is robust. It covers multiple areas including mitigation, resilience, recovery, societal learning, and various forms of benefits. These benefits include economic benefits and local/regional/state benefits. The planner's role in achieving this benefits cannot be disregarded. Each of these concepts and terms are explored in further detail below.

A major concept of this study is disaster mitigation, which can be defined as "…the actions taken by a community to eliminate or minimize the impact of a disaster" (Kennedy et al., 2013). This community can be at any level from neighbors to a state or country. Part of mitigation requires, "[t]he assessment of vulnerabilities, the development of infrastructure, memoranda of understanding, and planning for a sustainable response and recovery..." (Kennedy et al., 2013). These areas of mitigation are typically left to the governing entities to conduct.

Resilience can be viewed and defined through multiple lenses including economically, environmentally, and geographically. The overall concept of resilience can be viewed as, "the amount of disturbance a system can absorb…" which includes each of the systems mentioned above. Resilience is also viewed as the "concept of adaptive capacity…," and the ability of a system to recover after a disaster (Aldunce et al.; Klein, Nicholls, and Thomalla, 2015).

The next component of disaster mitigation and recovery is social learning. Residents of an area that is affected by a hurricane can learn through experience and through social learning. These two concepts are studied in articles by Derek Armitage and M. Keen. Armitage looks at experimental learning in Adaptive Co-Management and the Paradox of Learning. In this article, Armitage states that, "Learing is the transformation of experience, learning by doing" (Armitage, Marschke, and Plummer, 2008). Keen looks at learning through a social lens in Social Learning in Environmental Management: Towards a Sustainable Future. Keen states, "Social learning is a process of iterative reflection that occurs when we share our experiences…" (Keen, M., Brown, V., Dybal, 2005). These two theories point to the learning that takes places in a society through experiences of its members when these experiences are shared. Even though each person experiences the same situation differently, social learning can still be accomplished as each person still experienced the same event. This is the same type of learning that be useful in disasters such as hurricanes. Individuals can learn best practices from friends and neighbors about dealing with hurricanes and recovery from hurricanes. This can lead to increased resilience through socially learned mitigation efforts.

Rebuilding is a component of recovery and has a tangible effect on how a community withstands future disasters. One specific method of rebuilding that has components which are useful for hurricane recovery is the "Build Back Better," approached. In 2014, Chandra Laxmi Hada examined this approach in Supporting Earthquake Early Recovery in Eastern Nepal Through the "Building Back Better" Approach. This looks into recovery from earthquake activity in Nepal done through the auspice of the United Nations. It specifically looked at the selection, reconstruction, and renovation following the earthquake (Hada, 2015). This research indicates the methods used during rebuilding as part of a disaster recovery has an effect on future disaster results. Specifically, using methods in the from "Build Back Better," such as resilience planning, reconstruction rules and codes, and community training is beneficial to the effected community. The benefit can be seen immediately and in the form of disaster resilience during a subsequent disaster.

Another area that affects the mitigation and recovery process is the planner's role in the process. Understanding the planner's role to determine exactly where a planner fits into the process is important to successful mitigation and recovery. Karl Kim & Robert B. Olshansky do just this in The Theory and Practice of Building Back Better. They highlight that planners have a large part to play in recovering from a disaster due to their knowledge and abilities. These abilities can be applied in both the mitigation period and the recovery period. They also mention that few comparative studies exist on the disaster recovery process. This makes it difficult to know the best approaches to use in disaster recovery (Kim and Olshansky, 2014).

Another example of research showing the need for planners in the disaster mitigation and recovery process comes from a 2014 study, Adaptive Planning for Disaster Recovery and Resiliency: An Evaluation of 87 Local Recovery Plans in Eight States, by Philip Berke. This article studies disaster recovery at the local level with a focus on the need for appropriate planning. While this specific research does not delve deep into any one specific method, it does look at resources needed from planners. It also looks into the components of a recovery plan that can produce the best results (Berke et al., 2015).

DATA INFORMATION

The data for this research comes from two main sources. The first data source used comes from the Federal Emergency Management Agency (FEMA). One of the tasks of FEMA is to collect data from hazards and hazards that turn into disasters. FEMA gathers this information from a multitude of sources and then compiles the data into a publically available database. This data can be used in a FEMA software package, named HAZUS-MH, to study the effects of the hazard (Federal Emergency Management Agency, HAZUS 2015). This software can model the disaster and produce results on its affect.

The second data source comes from the state of South Carolina. Data compiled by the state from the county, city and census tract level was added to the HAZUS-MH program. All of this data is compatible with GIS software and is publically available (State of South Carolina, Geographic 2008).

RESEARCH DESIGN AND METHODOLOGY

The data obtained for this study was imported into the ESRI Arc GIS software program which can be used to spatially display and analyze the data. Then, the FEMA HAZUS-MH program was installed as an add-on to the Arc GIS software. The HAZUS-MH program, "is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods and hurricanes. HAZUS uses Geographic Information Systems (GIS) technology to estimate physical, economic and social impacts of disasters" (Federal Emergency Management Agency, HAZUS 2015). This program was used to model a hurricane and the resulting damaging to the State of South Carolina.

The HAZUS program breaks structures down into five main categories of wood, masonry, concrete, steel, and manufactured homes. These categories are further broken down by elements into subcategories such as year built, residential, business, and structure height. Each of these sections contain damage function curves with damage probabilities on the Y-axis and wind speeds on the X-axis. The damage curves are affected by any number of aspects including roof type, water resistance, shutters, and materials used. These factors were changed for the building stock inventory in South Carolina for each of the main categories and for the subcategories to determine the effect it would have on the damage caused by a hurricane. These damage curves have been included in the appendix.

HAZUS was chosen for the model as it is a widely used and successful tool for looking at disaster mitigation, resilience and recovery. According to FEMA, "HAZUS is used for mitigation and recovery, as well as preparedness and response. Government planners, GIS specialists and emergency managers use HAZUS to determine losses and the most beneficial mitigation approaches to take to minimize them" (Federal Emergency Management Agency, HAZUS 2015).

The building structure model that was used as a baseline for this study was the Southeast Inland model. This model covers almost the entire state of South Carolina which is why it was used as the base model for comparison. The other model is the Southeast Coast model which only covers the area of South Carolina directly on the coast. The Basic Wind Zone Map below shows the wind zones across the United States. The state of South Carolina has zones 1 and 2 within in its borders. Zone 1 is where the Southeast Inland model is derived from.

Figure 2: Basic Wind Zone Map

The hurricane that was used as the model for this research study comes from historical hurricanes that made landfall in the State of South Carolina. The hurricane chosen was Hurricane Hugo which made landfall in 1989. This hurricane had high enough sustained winds to allow for studying damage at midpoints in the damage curves but was not so big as to be unrealistic for future hurricane events. The storm path for this hurricane can be seen in the Hurricane Hugo Storm Path figure below.

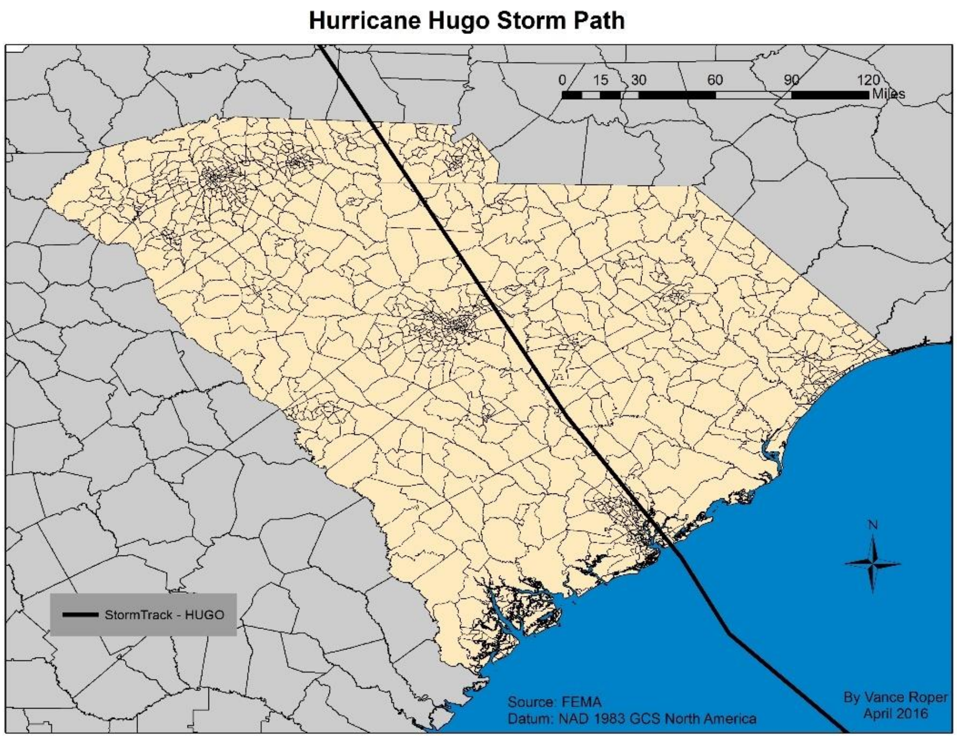


Figure 3: Hurricane Hugo Storm Path

The hurricane model discussed above was used for each scenario change as part of this study. As each building design variable was changed, the same hurricane model was used to assess any changes in building damage and economic loss. Only one variable was changed in each scenario run with the results being studied after each run.

The data for the structure inventory in all instances was a combination of FEMA data and data from the State of South Carolina. This data is an approximation based on information gained from these two sources and are not the exact numbers for the state. It is not possible to obtain the exact information for each structure in the state so this method provided the most accurate and best available data.

Part of this study required understanding where the different types of building stock where geographically located throughout the state. The number of buildings varied greatly between the five categories of wood, masonry, concrete, steel, and manufactured homes. To compensate for this and to have approximate display parity, each category was normalized by the percent of that structure type per census tract. This means that a lighter color in a census tract indicates that that area has a lower percent of that building type and a darker color means a higher percent of that building type in the area. An important fact to note is that the maps are not cross comparable resulting in each map being independent of the others. This means that a light color census tract of wood and dark color census tract of masonry in the same area does not mean that the census tract has more masonry buildings than wood. The five figures below display the number of buildings for each of the five categories. Each of these maps will also be contained in lager versions in the appendix.

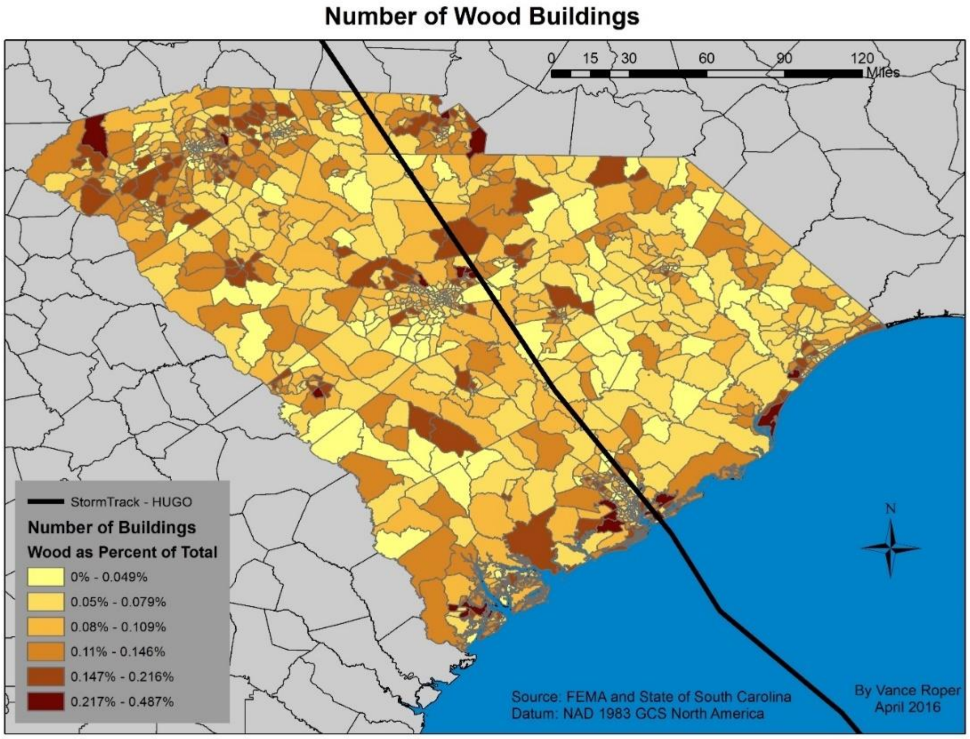


Figure 4: Number of Wood Buildings

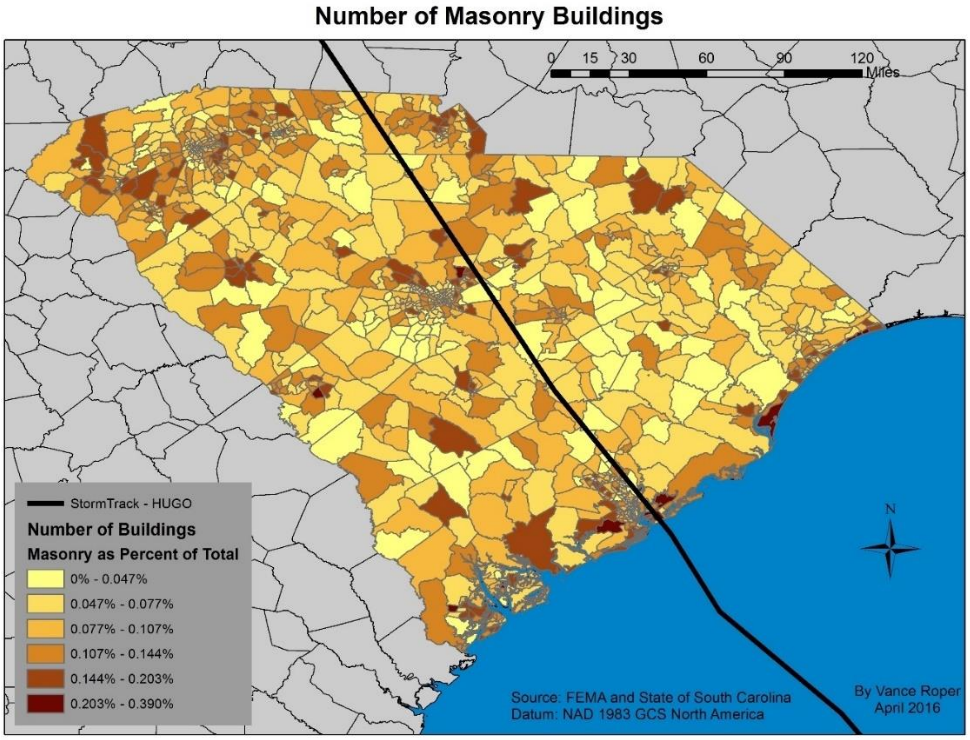


Figure 5: Number of Masonry Buildings

Number of Concrete Buildings

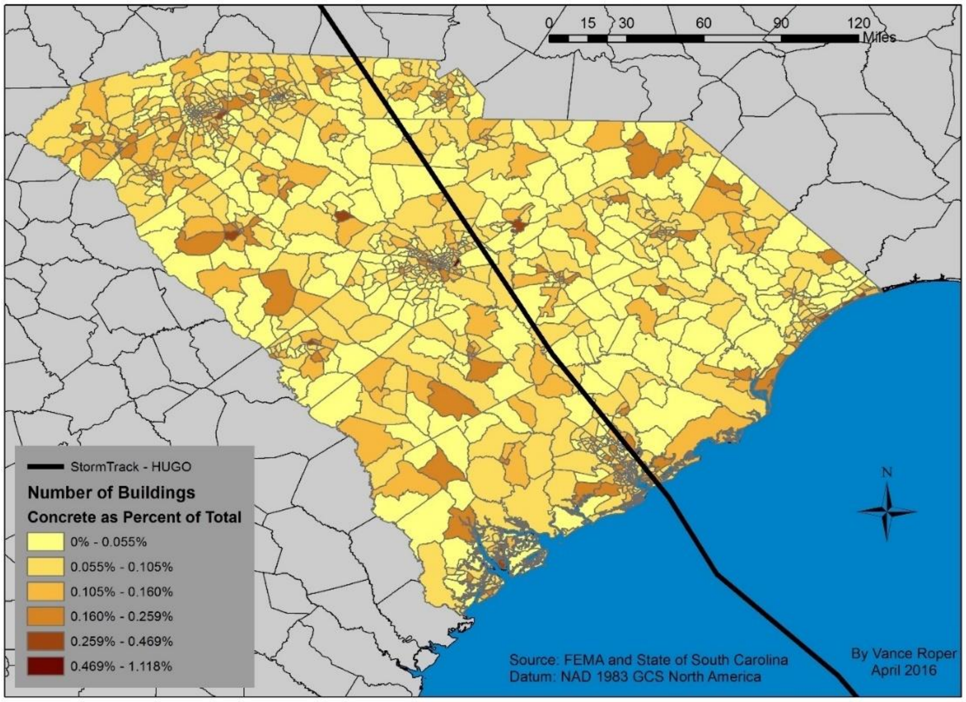


Figure 6: Number of Concrete Buildings

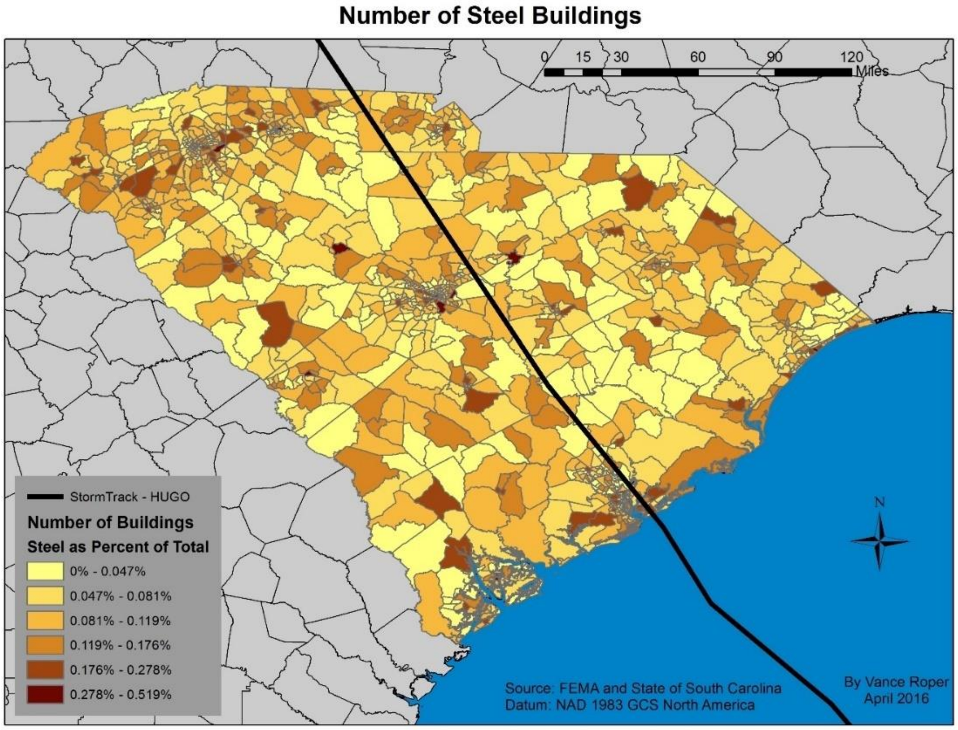


Figure 7: Number of Steel Buildings

Number of Manufactured Buildings

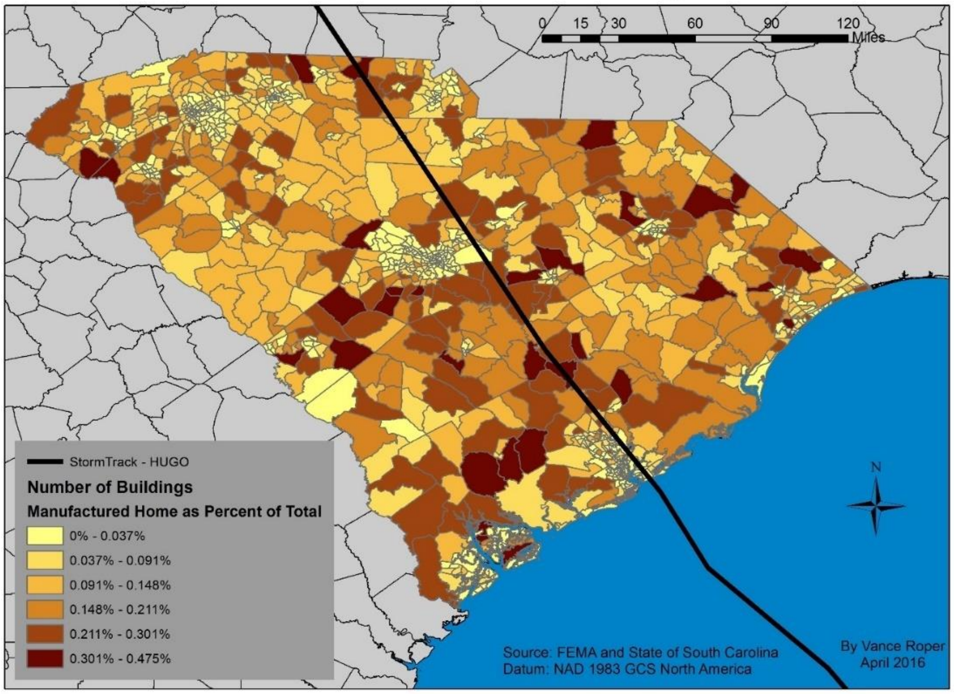


Figure 8: Number of Manufacture Buildings

This study used nine variables across the five building categories. These variables were secondary water resistance, roof shape, roof deck attachment, roof wall connections, shutters, reinforcement, roof cover, window area, and tie downs. All of these variables have explanations and examples below, with the exception of the first variable of window area. The window area variable ranges from low to high which indicates the amount of windows on the structure. As such, this variable has no corresponding figure example.

The second variable of secondary water resistance is meant as an additional protection against moisture and water damage. It is an intermediary surface between the outside and inside of the house. The figure below shows an example of a secondary water resistance barrier. In this example, the white moisture barrier is applied to the walls of the house and the black barrier is applied to the roof.

Figure 9: Secondary Water Resistance Example

The third variable of roof shape comes in three forms. The first form is flat which is precisely as it sounds, a flat surface covering the building. The second and third forms of gable had hip have angled roofs. Examples of the gable and hip roof can be found below in the Roof Shape Example figure.

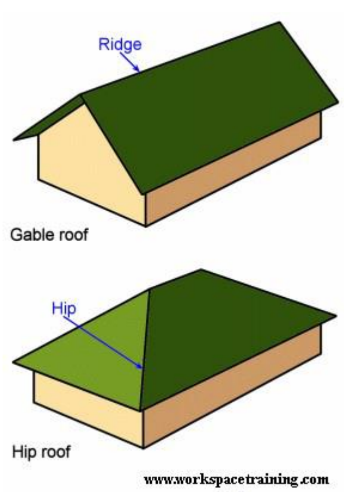


Figure 10: Roof Shape Example

The fourth variable of roof deck attachment refers to the type of fastener used to connect the roof deck. Nails are used in South Carolina and the options are 6d@6”/12”, 8d@6”/12”, 6d/8d mix@6”/6”, and 8D@6”/6”. The essential difference between these are the size of the nail. An example of the attachment can be seen in the Roof Deck Attachment Example figure below.

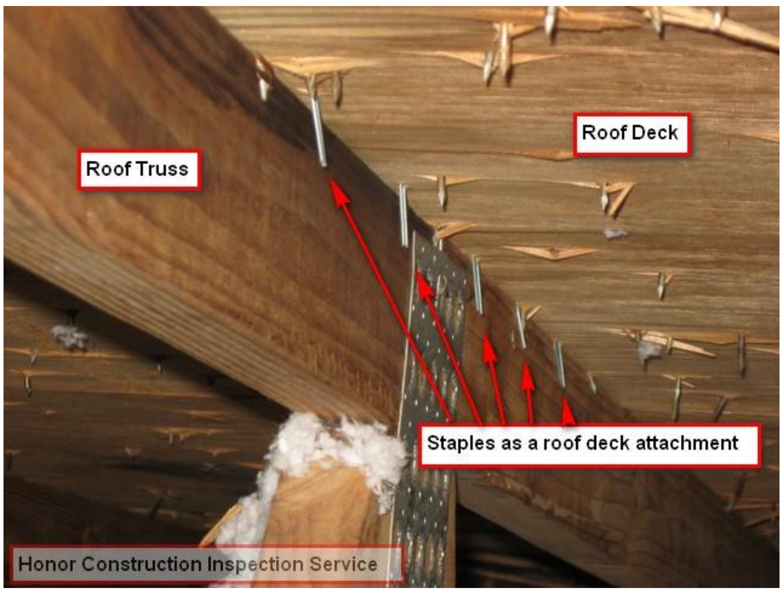


Figure 11: Roof Deck Attachment Example

The fifth variable of roof wall connections has two forms, which are strap and toe-nail. This frequency use of this variable (i.e. every connection or every other connection) is not an option in HAZUS. Each connection form deals with the connection between the beams on the roof of the structure and the wall of the structure. An example of each can be seen in the Roof Wall Connection Strap Example and Roof Wall Connection Toe-Nail Example figures below.

Figure 12: Roof Wall Connection Strap Example

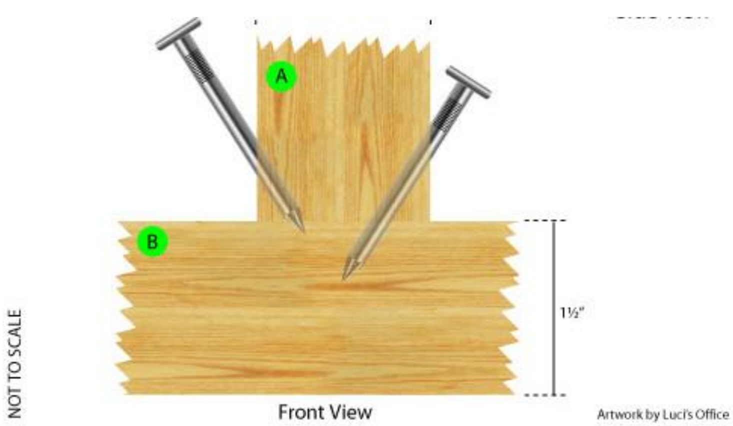


Figure 13: Roof Wall Connection Toe Nail Example

The sixth variable of shutters can indicate a wide variety of shutter types. The main objective of the shutter is protecting damage to the window and preventing debris from breaking into the house. An example of a shutter can be seen in the Shutter Example figure below.

Figure 14: Shutter Example

The seventh variable of reinforcement only applies to masonry structures. Reinforcement uses different types of metal to brace the masonry. These braces can be both vertical and horizontal. An example of this can be seen in the Reinforcement Example figure below.

Figure 15: Reinforcement Example

The eighth variable of roof cover has two options which are Built Up Roof (BUR) and Single Ply Membrane (SPM). These two roof types can be seen in the Roof Cover BUR Example and Roof Cover SPM Example figures below.

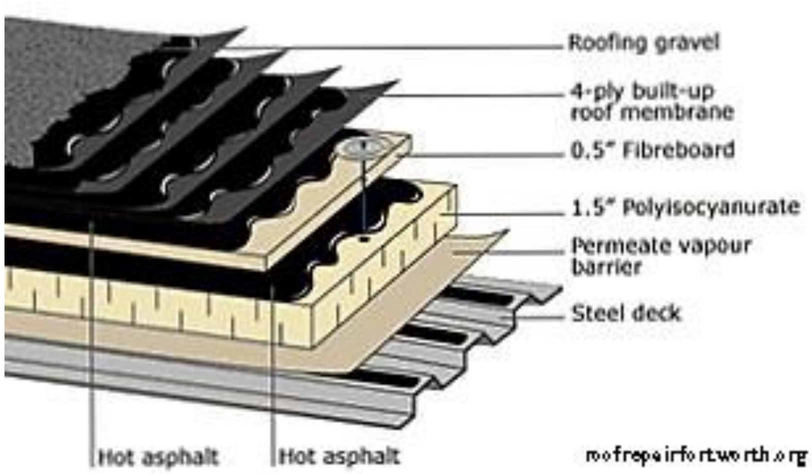


Figure 16: Roof Cover BUR Example

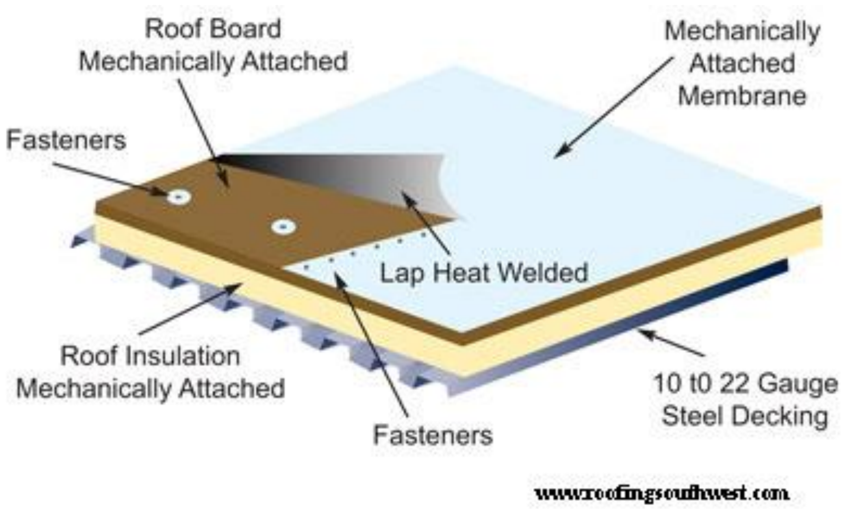


Figure 17: Roof Cover SPM Example

The ninth variable of tie downs is applicable only for manufactured homes. A tie down is a method to secure the home to the ground. An example of this can be seen in the Tie Down Example figure below.

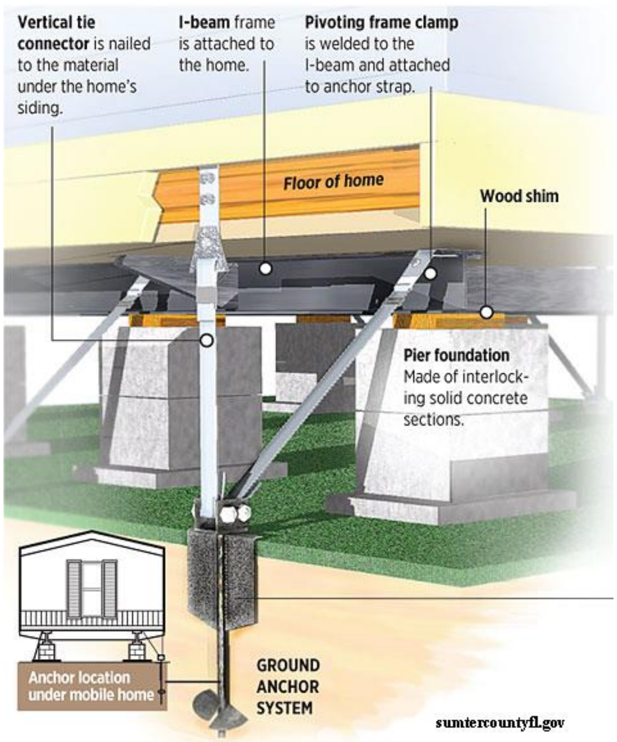


Figure 18: Tie Down Example

WOOD

The first category that was studied and changed was wood structures. The subcategories and acronyms for this category were derived from the FEMA HAZUS-MH program. The subcategories of wood are Wood Single Family Home with One Story (WSF1), Wood Single Family Home with Two or more Stories (WSF2), Wood Multi-Unit/Hotel/Motel with One Story (WMUH1), Wood Multi-Unit Hotel/Motel with Two

Stories (WMUH2), and Wood Multi-Unit Hotel/Motel with Three or more Stories (WMUH3).

Four building design variable changes were made to the model for wood structures based on the damage curves in the HAZUS-MH program as seen in Appendix. The first variable change was the secondary water resistance. The two options for the secondary water resistance variable are yes or no. The secondary water resistance breakdown for wood structures in South Carolina are contained in the Wood – Secondary Water Resistance Overview table below:

Wood - Secondary Water Resistance Overview		
Building Types	**Percent Yes**	**Percent No**
Wood Single Family Home with One Story	0	100
Wood Single Family Home with Two or more Stories	0	100
Wood Multi-Unit/Hotel/Motel with One Story	0	100
Wood Multi-Unit Hotel/Motel with Two Stories	0	100
Wood Multi-Unit Hotel/Motel with Three or more Stories	0	100

Table 1: Wood – Secondary Water Resistance Overview

The variable was changed in this scenario to 100 percent water resistance for all five subcategories of wood. This change was made as secondary water resistance slightly improves the damage curve.

The second variable change was the roof shape. The three types of roof shapes in South Carolina are flat, gable and hip with the exception of WSF1 and WSF2 which only have gable and hip. The roof shape breakdown for the wood structures in South Carolina are contained in the Wood - Roof Shape Overview table below:

Wood – Roof Shape Overview			
Building Types	**Percent Flat**	**Percent Gable**	**Percent Hip**
Wood Single Family Home with One Story	---	95	5
Wood Single Family Home with Two or more Stories	---	93	7
Wood Multi-Unit/Hotel/Motel with One Story	17	83	0
Wood Multi-Unit Hotel/Motel with Two Stories	0	93	7
Wood Multi-Unit Hotel/Motel with Three or more Stories	0	93	7

Table 2: Wood – Roof Shape Overview

The variable change for this scenario moved all 5 subcategories to 100 percent hip. This was done as the hip roof shape provided the damage curves with the best resistance to hurricane damage. Flat roof shapes provided damage curves with the least resistance to hurricane damage.

The third variable change was the roof deck attachment. The types of roof deck attachment for wood are 6d@6”/12”, 8d@6”/12”, 6d/8d mix@6”/6”, and 8D@6”/6”. The roof deck attachment breakdown for wood structures in South Carolina are contained in the Wood – Roof Deck Attachment table below

Wood – Roof Deck Attachment Overview				
Building Types	**Percent 6d@6"/12"**	**Percent 8d@6"/12"**	**Percent 6d/8d mix@6"/6"**	**Percent 8D@6"/6"**
Wood Single Family Home with One Story	44	34	0	22
Wood Single Family Home with Two or more Stories	44	34	0	22
Wood Multi-Unit/Hotel/Motel with One Story	44	56	0	0
Wood Multi-Unit Hotel/Motel with Two Stories	44	56	0	0
Wood Multi-Unit Hotel/Motel with Three or more Stories	44	56	0	0

Table 3: Wood – Roof Deck Attachment Overview

The damage curves for this section showed that the 8D @ 6"/6" produced the best results. These results were slightly better than the 6d/8d@6"/6" and a great deal better than the other two options. The variable change for this scenario moved all subcategories to 8D@6"/6".

The fourth variable change was the roof wall connection. The two types of connections for wood structures are toe-nail and strap. The roof wall connection breakdown for the wood structures in South Carolina are contained in the Wood – Roof Wall Connections Overview table below:

Wood – Roof Wall Connection Overview		
Building Types	**Percent Toe-Nail**	**Percent Strap**
Wood Single Family Home with One Story	37	63
Wood Single Family Home with Two or more Stories	37	63
Wood Multi-Unit/Hotel/Motel with One Story	37	63
Wood Multi-Unit Hotel/Motel with Two Stories	37	63
Wood Multi-Unit Hotel/Motel with Three or more Stories	37	63

Table 4: Wood – Roof Wall Connections

The damage curves for the strap connections produced the best results so the variable change for this scenario moved all wood structures to 100 percent strap.

MASONRY

The second category that was studied and changed was masonry structures. The subcategories and acronyms for this category were derived from the FEMA HAZUS-MH program. The subcategories of masonry are Masonry Single Family Home with One Story (MSF1), Masonry Single Family Home with Two or more Stories (MSF2), Masonry Multi-Unit/Hotel/Motel with One Story (MMUH1), Masonry Multi-Unit/Hotel/Motel with Two Stories (MMUH2), Masonry Multi-Unit/Hotel/Motel with Three or more Stories (MMUH3), Masonry Low-Rise Strip Mall up to 15 Feet High (MLRM1), Masonry Low-Rise Strip Mall more than 15 Feet High (MLRM2), Masonry Low-Rise Warehouse/Factory 20 Feet High (MLRI), Masonry Engineered Residential

Buildings 1-2 Stories (MERBL), Masonry Engineered Residential Buildings 3-5 Stories (MERBM), Masonry Engineered Residential Buildings 6 or more Stories (MERBH), Masonry Engineered Commercial Buildings 1-2 Stories (MECBL), Masonry Engineered Commercial Buildings 3-5 Stories (MECBM), and Masonry Engineered Commercial Buildings 6 or more Stories (MECBH).

Seven building design variable changes were made to the model for masonry structures based on the damage curves in the HAZUS-MH program as seen in the Appendix. The first variable change was secondary water resistance. The two options for the secondary water resistance variable are yes or no. The secondary water resistance breakdown for masonry structures in South Carolina are contained in the Masonry – Secondary Water Resistance Overview table below:

Masonry – Secondary Water Resistance Overview		
Building Types	**Percent Yes**	**Percent No**
Masonry Single Family Home with One Story	0	100
Masonry Single Family Home with Two or more Stories	0	100
Masonry Multi-Unit/Hotel/Motel with One Story	0	100
Masonry Multi-Unit/Hotel/Motel with Two Stories	0	100
Masonry Multi-Unit/Hotel/Motel with Three or more Stories	0	100

Table 5: Masonry – Secondary Water Resistance Overview

The subcategories of MLRMI, MLRM2, MLRI, MERBL, MERBM, MERBH, MECBL, MECBM, and MECBH do not have the option of secondary water resistance. In this scenario the variable was changed to 100 percent water resistance for the five subcategories of masonry that have this variable option. This change was made as secondary water resistance slightly improves the damage curve.

The second variable change was the roof shape. The three types of roof shapes for masonry in South Carolina are flat, gable, and hip with the exception of MSF1 and MSF2 which only has the gable and hip roof shapes. The roof shape breakdown for masonry structures in South Carolina are contained in the Masonry – Roof Shape Overview table below:

Masonry – Roof Shape Overview			
Building Types	**Percent Flat**	**Percent Gable**	**Percent Hip**
Masonry Single Family Home with One Story	---	56	44
Masonry Single Family Home with Two or more Stories	---	73	27
Masonry Multi-Unit/Hotel/Motel with One Story	19	66	15
Masonry Multi-Unit/Hotel/Motel with Two Stories	19	66	15
Masonry Multi-Unit/Hotel/Motel with Three or more Stories	19	66	15

Table 6: Masonry – Roof Shape Overview

The subcategories of MLRM1, MLRM2, MLRI, MERBL, MERBM, MERBH, MECBL, MECBM, and MECBH do not have the option of roof shapes. The variable change for this scenario moved the 5 subcategories with this variable to 100 percent hip. This was done as the hip roof shape provided the damage curves with the best resistance to hurricane damage. Flat roof shapes provided damage curves with the least resistance to hurricane damage.

The third variable change made was the roof deck attachment. The types of roof deck attachment for masonry are 6d@6"/12", 8d@6"/12", 6d/8d mix@6"/6", and 8D@6"/6". The roof deck attachment breakdown for masonry structures in South Carolina are contained in the Masonry – Roof Deck Attachment Overview table below:

Masonry – Roof Deck Attachment Overview				
Building Types	**Percent 6d@6"/12"**	**Percent 8d@6"/12"**	**Percent 6d/8d mix@6"/6"**	**Percent 8D@6"/6"**
Masonry Single Family Home with One Story	44	34	0	22
Masonry Single Family Home with Two or more Stories	44	34	0	2
Masonry Multi-Unit/Hotel/Motel with One Story	44	56	0	0
Masonry Multi-Unit/Hotel/Motel with Two Stories	44	56	0	0
Masonry Multi-Unit/Hotel/Motel with Three or more Stories	44	56	0	0
Masonry Low-Rise Strip Mall up to 15 Feet High	44	56	0	0
Masonry Low-Rise Strip Mall more than 15 Feet High	44	56	0	0

Table 7: Masonry – Roof Deck Attachment Overview

The subcategories of MLRI, MERBL, MERBM, MERBH, MECBL, MECBM, and MECBH do not have the option of roof deck attachment. The damage curves for this section showed that the 8D @ 6”/6” produced the best results. These results were slightly better than the 6d/8d@6”/6” and a great deal better than the other two options. The variable change for this scenario moved all subcategories to 8D@6”/6”.

The fourth variable change was the roof wall connections. The two types of connections for masonry structures are toe-nail and strap. The roof-wall connection breakdown for masonry structures in South Carolina are contained in the Masonry - Roof Wall Connections Overview table below:

Masonry – Roof Wall Connections Overview		
Building Types	**Percent Toe-Nail**	**Percent Strap**
Masonry Single Family Home with One Story	31	69
Masonry Single Family Home with Two or more Stories	31	69
Masonry Multi-Unit/Hotel/Motel with One Story	31	69
Masonry Multi-Unit/Hotel/Motel with Two Stories	31	69
Masonry Multi-Unit/Hotel/Motel with Three or more Stories	31	69
Masonry Low-Rise Strip Mall up to 15 Feet High	31	69
Masonry Low-Rise Strip Mall more than 15 Feet High	31	69

Table 8: Masonry – Roof Wall Connections Overview

The subcategories of MLRI, MERBL, MERBM, MERBH, MECBL, MECBM, and MECBH do not have a roof wall connection variable option. The damage curves for the strap connections produced the best results so the variable change for this scenario moved the masonry structures with this variable to 100 percent strap.

The fifth variable change was shutters. The two options for the shutter variable are yes or no. The shutter breakdown for masonry structures in South Carolina are contained in the Masonry – Shutter Overview table below:

Masonry – Shutter Overview		
Building Types	**Percent Yes**	**Percent No**
Masonry Single Family Home with One Story	0	100
Masonry Single Family Home with Two or more Stories	0	100
Masonry Multi-Unit/Hotel/Motel with One Story	0	100
Masonry Multi-Unit/Hotel/Motel with Two Stories	0	100
Masonry Multi-Unit/Hotel/Motel with Three or more Stories	0	100
Masonry Low-Rise Strip Mall up to 15 Feet High	0	100
Masonry Low-Rise Strip Mall more than 15 Feet High	0	100
Masonry Low-Rise Warehouse/Factory 20 Feet High	0	100
Masonry Engineered Residential Buildings 1-2 Stories	0	100
Masonry Engineered Residential Buildings 3-5 Stories	0	100
Masonry Engineered Residential Buildings 6 or more Stories	0	100
Masonry Engineered Commercial Buildings 1-2 Stories	0	100
Masonry Engineered Commercial Buildings 3-5 Stories	0	100
Masonry Engineered Commercial Buildings 6 or more Stories	0	100

Table 9: Masonry – Shutter Overview

Shutters produced a minimal change in the damage curves. This could be for many reasons including lack of use during a storm or lack of functionality due to the decorative nature of some shutters. The shutter variable on all fourteen subcategories where changed to 100 percent yes. Two subcategories, MSF1 and MSF2, had an additional option of garages with shutters. The option of this category was none and SFBC 1994. This was set to 100 percent SFBC 1994.

The sixth variable change was masonry reinforcement. The two options for the masonry reinforcement variable are yes or no. The masonry reinforcement breakdown for masonry structures in South Carolina are contained in the Masonry – Reinforcement Overview table below:

Masonry – Reinforcement Overview		
Building Types	**Percent Yes**	**Percent No**
Masonry Single Family Home with One Story	30	70
Masonry Single Family Home with Two or more Stories	30	70
Masonry Multi-Unit/Hotel/Motel with One Story	30	70
Masonry Multi-Unit/Hotel/Motel with Two Stories	30	70
Masonry Multi-Unit/Hotel/Motel with Three or more Stories	30	70
Masonry Low-Rise Strip Mall up to 15 Feet High	30	70
Masonry Low-Rise Strip Mall more than 15 Feet High	30	70
Masonry Low-Rise Warehouse/Factory 20 Feet High	30	70

Table 10: Masonry – Reinforcement Overview

The subcategories of MERBL, MERBM, MERBH, MECBL, MECBM, and MECBH do not have a masonry reinforcement option. Masonry reinforcement produced a damage curve with better resistance to hurricanes. For this variable, the masonry structures with this option were changed to 100 percent yes for masonry reinforcement.

The seventh variable change was roof cover. The two options for the roof cover variable are BUR and SPM. The roof cover breakdown for masonry structures in South Carolina are contained in the Masonry – Roof Cover Overview table below.

Masonry – Roof Cover Overview		
Building Types	**Percent BUR**	**Percent SPM**
Masonry Multi-Unit/Hotel/Motel with One Story	85	15
Masonry Multi-Unit/Hotel/Motel with Two Stories	85	15
Masonry Multi-Unit/Hotel/Motel with Three or more Stories	85	15
Masonry Low-Rise Strip Mall up to 15 Feet High	85	15
Masonry Low-Rise Strip Mall more than 15 Feet High	85	15
Masonry Engineered Residential Buildings 1-2 Stories	85	15
Masonry Engineered Residential Buildings 3-5 Stories	85	15
Masonry Engineered Residential Buildings 6 or more Stories	85	15
Masonry Engineered Commercial Buildings 1-2 Stories	85	15
Masonry Engineered Commercial Buildings 3-5 Stories	85	15
Masonry Engineered Commercial Buildings 6 or more Stories	85	15

Table 11: Masonry – Roof Cover Overview

The subcategories of MSF1, MSF2, and MLRI do not have a roof cover option. The BUR roof cover variable was changed to 100% BUR for the subcategories with that option as it produced a more resilient damage curve as compared with SPM roof shape.

CONCRETE

The third category that was studied and changed was concrete structures. The subcategories and acronyms for this category were derived from the FEMA HAZUS-MH program. The subcategories of concrete are Concrete Engineered Residential Buildings 1-2 Stories (CERBL), Concrete Engineered Residential Buildings 3-5 Stories (CERBM), Concrete Engineered Residential Buildings 6 or more Stories (CERBH), Concrete Engineered Commercial Buildings 1-2 Stories (CECBL), Concrete Engineered Commercial Buildings 3-5 Stories (CECBM), and Concrete Engineered Commercial Buildings 6 or more Stories (CECBH).

Three building design variable changes were made to the model for concrete structures based on the damage curves in the HAZUS-MH program as seen in the Appendix. The first variable change was shutters. The two options for the shutter variable are yes or no. The shutter breakdown for concrete structures in South Carolina are contained in the Concrete – Shutter Overview table below:

Concrete – Shutter Overview		
Building Types	**Percent Yes**	**Percent No**
Concrete Engineered Residential Buildings 1-2 Stories	0	100
Concrete Engineered Residential Buildings 3-5 Stories	0	100
Concrete Engineered Residential Buildings 6 or more Stories	0	100
Concrete Engineered Commercial Buildings 1-2 Stories	0	100
Concrete Engineered Commercial Buildings 3-5 Stories	0	100
Concrete Engineered Commercial Buildings 6 or more Stories	0	100

Table 11: Concrete – Shutter Overview

Shutters produce a minimal change in the damage curves. The shutter variable on all subcategories of concrete where changed to 100 percent yes.

The second variable change was the roof cover. The two options for the roof cover variable are BUR and SPM. The roof cover breakdown for concrete structures in South Carolina are contained in the Concrete - Roof Cover Overview table below:

Concrete – Roof Cover Overview		
Building Types	**Percent BUR**	**Percent SPM**
Concrete Engineered Residential Buildings 1-2 Stories	85	15
Concrete Engineered Residential Buildings 3-5 Stories	85	15
Concrete Engineered Residential Buildings 6 or more Stories	85	15
Concrete Engineered Commercial Buildings 1-2 Stories	85	15
Concrete Engineered Commercial Buildings 3-5 Stories	85	15
Concrete Engineered Commercial Buildings 6 or more Stories	85	15

Table 12: Concrete – Roof Cover Overview

The BUR roof cover variable was changed to 100% BUR for all the concrete subcategories as it produced a more resilient damage curve as compared with SPM roof shape.

The third variable change made was the window area. The three options for window area are low, medium, and high. The window area breakdown for concrete structures in South Carolina are contained in the Concrete – Window Area Overview table below.

Concrete – Window Area Overview			
Building Types	**Percent Low**	**Percent Medium**	**Percent High**
Concrete Engineered Residential Buildings 1-2 Stories	77	11	12
Concrete Engineered Residential Buildings 3-5 Stories	77	11	12
Concrete Engineered Residential Buildings 6 or more Stories	77	11	12
Concrete Engineered Commercial Buildings 1-2 Stories	77	11	12
Concrete Engineered Commercial Buildings 3-5 Stories	77	11	12
Concrete Engineered Commercial Buildings 6 or more Stories	77	11	12

Table 13: Concrete – Window Area Overview

The low window area variable provided the best resilience to hurricanes according to the damage curves with high window area providing the worst resilience. All subcategories of concrete were changed to 100 percent low window area for this scenario run.

STEEL

The fourth category that was studied and changed was steel structures. The subcategories and acronyms for this category were derived from the FEMA HAZUS-MH program. The subcategories of steel are Steel Pre-Engineered Metal Building Small

(SPMBS), Steel Pre-Engineered Metal Building Medium (SPMBM), Steel Pre-Engineered Metal Building Large (SPMBL), Steel Engineered Residential Buildings 1-2 Stories (SERBL), Steel Engineered Residential Buildings 3-5 Stories (SERBM), Steel Engineered Residential Buildings 6 or more Stories (SERBH), Steel Engineered Commercial Buildings 1-2 Stories (SECBL), Steel Engineered Commercial Buildings 3-5 Stories (SECBM), and Steel Engineered Commercial Buildings 6 or more Stories (SECBH).

Four building design variable changes were made to the model for steel structures based on the damage curves in the HAZUS-MH program as seen in the Appendix. The first variable change was roof deck attachment. The two options for the roof deck attachment are standard and superior. The roof deck attachment breakdown for steel structures in South Carolina are contained in the Steel – Roof Deck Attachment Overview table below:

Steel – Roof Deck Attachment Overview		
Building Types	**Percent Standard**	**Percent Superior**
Steel Pre-Engineered Metal Building Small	100	0
Steel Pre-Engineered Metal Building Medium	100	0
Steel Pre-Engineered Metal Building Large	100	0
Steel Engineered Residential Buildings 1-2 Stories	100	0
Steel Engineered Residential Buildings 3-5 Stories	100	0
Steel Engineered Residential Buildings 6 or more Stories	100	0
Steel Engineered Commercial Buildings 1-2 Stories	100	0
Steel Engineered Commercial Buildings 3-5 Stories	100	0
Steel Engineered Commercial Buildings 6 or more Stories	100	0

Table 14: Steel - Roof Deck Attachment Overview

The superior option for this variable provides the best resilience to hurricanes so this option was set to 100 percent for all subcategories or steel.

The second variable change made was shutters. The two options for the shutter variable are yes or no. The shutter breakdown for steel structures in South Carolina are contained in the Steel – Shutter Overview table below:

Steel – Shutter Overview		
Building Types	**Percent Yes**	**Percent No**
Steel Pre-Engineered Metal Building Small	0	100
Steel Pre-Engineered Metal Building Medium	0	1000
Steel Pre-Engineered Metal Building Large	0	100
Steel Engineered Residential Buildings 1-2 Stories	0	100
Steel Engineered Residential Buildings 3-5 Stories	0	100
Steel Engineered Residential Buildings 6 or more Stories	0	100
Steel Engineered Commercial Buildings 1-2 Stories	0	100
Steel Engineered Commercial Buildings 3-5 Stories	0	100
Steel Engineered Commercial Buildings 6 or more Stories	0	100

Table 15: Steel – Shutter Overview

Shutters produce a minimal change in the damage curves. The shutter variable on all subcategories of steel where changed to 100 percent yes.

The third variable change was roof cover. The two options for the roof cover variable are BUR and SPM. The roof cover breakdown for steel structures in South Carolina are contained in the Steel – Roof Cover Overview table below:

Steel – Roof Cover Overview		
Building Types	**Percent BUR**	**Percent SPM**
Steel Engineered Residential Buildings 1-2 Stories	85	15
Steel Engineered Residential Buildings 3-5 Stories	85	15
Steel Engineered Residential Buildings 6 or more Stories	85	15
Steel Engineered Commercial Buildings 1-2 Stories	85	15
Steel Engineered Commercial Buildings 3-5 Stories	85	15
Steel Engineered Commercial Buildings 6 or more Stories	85	15

Table 16: Steel – Roof Cover Overview

The subcategories of SPMBS, SPMBM, and SPMBL do not have the option of roof cover type. The BUR roof cover variable was changed to 100% BUR for all the steel subcategories with this option as it produced a more resilient damage curve as compared with SPM roof shape.

The fourth variable change was window area. The three options for window area are low, medium, and high. The window area breakdown for steel structures in South Carolina are contained in the Steel – Window Area Overview table below:

Steel – Window Area Overview			
Building Types	**Percent Low**	**Percent Medium**	**Percent High**
Steel Engineered Residential Buildings 1-2 Stories	77	11	12
Steel Engineered Residential Buildings 3-5 Stories	77	11	12
Steel Engineered Residential Buildings 6 or more Stories	77	11	12
Steel Engineered Commercial Buildings 1-2 Stories	77	11	12
Steel Engineered Commercial Buildings 3-5 Stories	77	11	12
Steel Engineered Commercial Buildings 6 or more Stories	77	11	12

Table 17: Steel – Window Area Overview

The subcategories of SPMBS, SPMBM, and SPMBL do not have the option of window area. The low window area variable provided the best resilience to hurricanes according to the damage curves with high window area providing the worst resilience. All subcategories of steel with this variable option were changed to 100 percent low window area for this scenario run.

MANUFACTURED HOME

The fifth category that was studied and changed was manufactured home structures. The subcategories and acronyms for this category were derived from the FEMA HAZUS-MH program. The subcategories of manufactured homes are Manufactured Home Before 1976 (MHPHUD), Manufactured Home 1976 - 1994

(MH76HUD), Manufactured Home After 1994 Zone 1 (MH94HUDI), Manufactured Home After 1994 Zone 2 (MH94HUDII), and Manufactured Home After 1994 Zone 3 (MH94HUDIII).

Two building design variable changes were made to the model for wood structures based on the damage curves in the HAZUS-MH program as seen in the Appendix. The first variable change was shutters. The two options for the shutter variable are yes or no. The shutter breakdown for manufactured homes in South Carolina are contained in the Manufactured Home Shutter Overview table below:

Manufactured Home – Shutter Overview		
Building Types	**Percent Yes**	**Percent No**
Manufactured Home Before 1976	0	100
Manufactured Home 1976 - 1994	0	100
Manufactured Home After 1994 Zone 1	0	100
Manufactured Home After 1994 Zone 2	0	100
Manufactured Home After 1994 Zone 3	0	100

Table 18: Manufactured Home - Shutter Overview

Shutters produce a minimal change in the damage curves. The shutter variable on all subcategories of manufactured homes where changed to 100 percent yes.

The second variable change was tie downs. The two options for the tie down variable are yes and no. The tie down breakdown for manufactured homes in South Carolina are contained in the Manufactured Home – Tie Down Overview table below.

Manufactured Home – Tie Down Overview		
Building Types	**Percent Yes**	**Percent No**
Manufactured Home Before 1976	50	50
Manufactured Home 1976 - 1994	75	25
Manufactured Home After 1994 Zone 1	99	1
Manufactured Home After 1994 Zone 2	99	1
Manufactured Home After 1994 Zone 3	99	1

Table 19: Manufactured Home – Tie Down Overview

Tie downs provide more resilience to hurricane damage so this option was changed to 100 percent yes for all subcategories of manufactured homes.

RESULTS AND ANALYSIS

The results of the analysis provided some interesting and useful information. The process was cyclical and started with the un-altered data. The variables discussed above were changed one at a time to determine its effect on the model. The Process Diagram figure below illustrates this process.

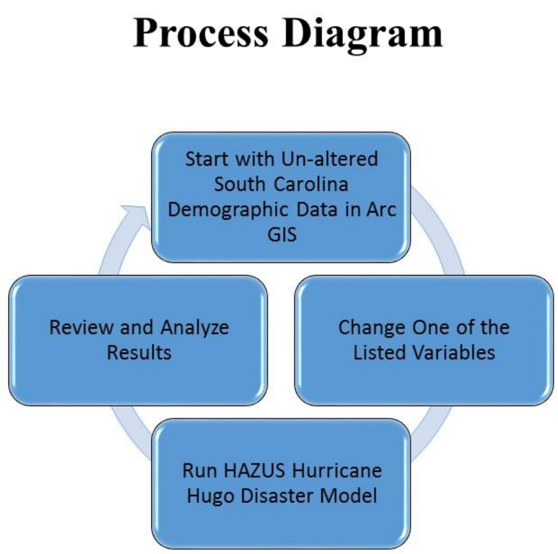


Figure 19: Process Diagram

A baseline analysis was run to compare each of the variable changes to. This baseline run kept all variables unchanged as they were reported in the methods section. The baseline model was run five times to insure that no changes occurred to the resulting data. Each of the five baseline model runs produced the same results.

The FEMA HAZUS program breaks the damage categories down into none, minor, moderate, severe, and destruction. While the FEMA HAZUS program uses this terminology, the FEMA standard operating procedure uses the terminology of affected (in replacement of minor), minor (in replacement of moderate), major (in replacement of severe), and destruction (which remains the same). These terms are interchangeable. The definitions of these terms are contained in its entirety below.

> "**Affected** - This category includes dwellings with minimal damage to structure and/or contents and the home is habitable without repairs….
>
> **Minor** - Minor damage encompasses a wide range of damage and is generally the most common type of damage. Minor damage exists when the home is damaged and uninhabitable, but may be made habitable in a short period of time with home repairs. Some of the items that determine minor damage are listed below:
>
> - Damages less than the maximum Housing Assistance Repair Grant.
> - Windows or doors blown in.
> - One foot or more of water/sewer backup in basement (i.e., furnace, water heater damage).
> - Has less than 50% damage to structure…
>
> **Major** - Major damage exists when the home has sustained structural or significant damages, is uninhabitable and requires extensive repairs. Any one of the following may constitute major damage.
>
> - Substantial failure of structural elements of the residence (e.g., walls, roof, floors, foundation, etc.).
> - Damage to the structure that exceeds the Home Repair Grant maximum.
> - Has more than 50% damage to structure.
> - One foot or more of water on the first floor (of a home with basement)…
>
> **Destroyed** - Destroyed means the structure is a total loss or damaged to such an extent that repairs are not economically feasible. Any one of the following may constitute a status of destroyed:
>
> - Structure is not economically feasible to repair.
> - Structure is permanently uninhabitable.
> - Complete failure of major structural components (e.g., collapse of basement walls/foundation, walls, or roof).
> - Only foundation remains.
> - Two or more walls destroyed and roof substantially damaged.
> - House pushed off foundation
> - An unaffected structure that will require removal or demolition (e.g., homes in imminent danger due to impending landslides, mudslides, or sinkholes; beachfront homes that must be removed due to local ordinance violations as a result of beach erosion)" (Federal Emergency Management Agency, Preliminary Damage Assessment 2015).

The Baseline Run Damage Table below shows the results from the base line run for this model. The count column under each of these damage categories represents the number of buildings damaged and the percent column represents the percent of total buildings in the state for that building type that were damaged. The total number of buildings with no damage was 1,722,956, minor damage was 173,462, moderate damage was 61,308, severe damage was 12,903, and buildings that were destroyed was 5,480.

Baseline Run Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Wood	1,133,351	84.44	151,081	11.26	44,626	3.32	8,772	0.65	4,349	0.32
Masonry	144,534	84.16	14,838	8.64	9,993	5.82	2,105	1.23	262	0.15
Concrete	13,649	84.35	1,156	7.15	1,087	6.72	289	1.79	0	0.00
Steel	56,114	85.92	3,967	6.07	3,663	5.61	1,531	2.34	34	0.05
MH	375,308	98.58	2,420	0.64	1,939	0.51	206	0.05	835	0.22

Table 20: Baseline Run Damage

The Baseline Run Economic Results Table below displays the economic effects from the baseline model run. The table is broken down into the categories of property damage, business interruption loss and total loss. Property damage is broken down into the subcategories of building damage costs, content loss cost, and inventory loss cost. Business loss interruption is broken down into subcategories of income loss, relocation loss, rental costs, and wage loss. The four major categories of buildings across the top of the table are the residential category, commercial category, industrial category, and others category. The total loss for the baseline run was almost $13 million for the residential category, just over $1.5 million for the commercial category, almost $500,000 for the industrial category, and just over $300,000 for the other category.

Baseline Run Economic Results							
Category		**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage							
		Building	$8,438,006.99	$740,673.70	$227,176.29	$155,509.12	$9,561,366.09
		Content	$3,084,412.56	$404,376.09	$171,793.62	$78,423.96	$3,739,006.23
		Inventory	$0.00	$10,836.84	$28,825.22	$1,425.02	$41,087.08
		Subtotal	**$11,522,419.55**	**$1,155,886.63**	**$427,795.13**	**$235,358.10**	**$13,341,459.40**
Business Interruption Loss							
		Income	$5,357.62	$104,695.00	$3,399.81	$7,083.91	$120,536.34
		Relocation	$966,996.14	$142,016.93	$19,140.33	$37,638.83	$1,165,792.24
		Rental	$359,436.37	$75,975.70	$3,103.18	$3,712.58	$442,227.83
		Wage	$12,549.30	$103,970.51	$5,497.37	$31,309.19	$153,326.38
		Subtotal	**$1,344,339.42**	**$426,658.15**	**$31,140.70**	**$79,744.52**	**$1,881,882.79**
Total							
		Total	**$12,866,758.97**	**$1,582,544.78**	**$458,935.83**	**$315,102.61**	**$15,223,342.19**

Table 21: Baseline Run Economic Results

Each of the tables below represent the difference between the baseline run and the respective scenario runs with variable changes. The difference was obtained by subtracting the baseline results from the results from each variable change scenario run. All the tables follow the same format as the baseline run tables above.

WOOD

The damage to wood follows the typically hurricane pattern with the majority of the damage being experienced on the right side of the storm and at the landfall zone of the hurricane. The map below highlights the damaged caused by Hurricane Hugo and includes all types of damage from minor to destruction. The damage scale moves from green for no damage to red for complete damage.

Wood - At Least Minor Damage

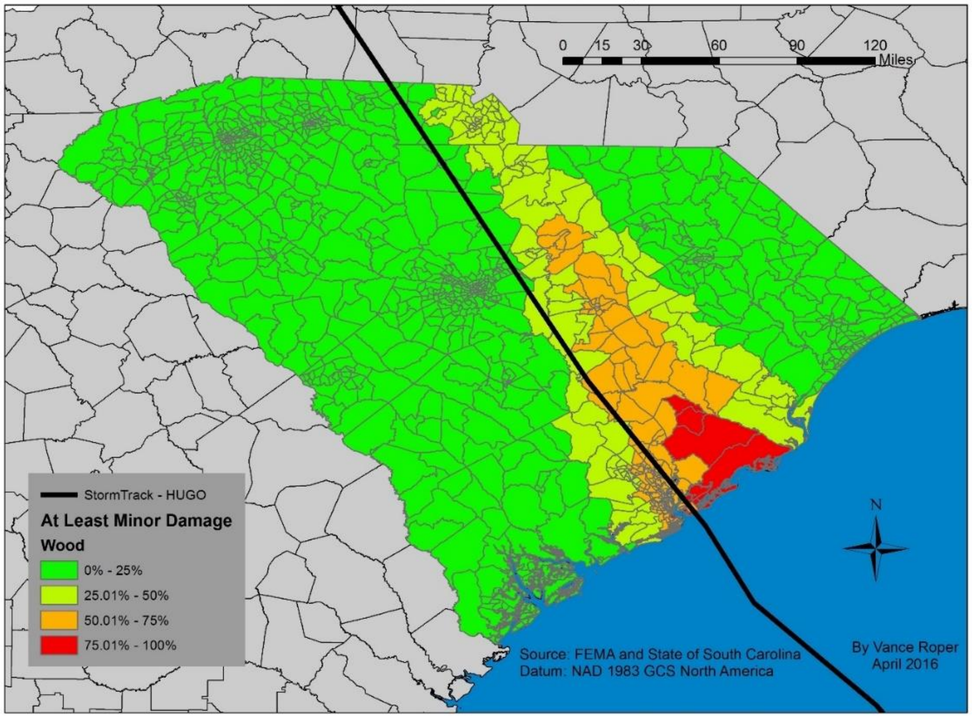


Figure 20: Wood – At Least Minor Damage

Secondary Water Resistance

The first variable change of secondary water resistance produced conflicting results on the number of buildings damaged versus the cost of damage. The Wood - Secondary Water Resistance Damage table displays the results from this variable change. The number of building that received no damage dropped by 0.8 percent which resulted in just under an 11,000 drop in the number of buildings that received no damage. The number of buildings that received minor to moderate damage increased by 7,779 buildings. The number of buildings that received severe damage or that were destroyed increased by 0.23 percent which equates to 2,950 buildings.

Secondary Water Resistance Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Wood	-10,729	-0.80	4,705	0.35	3,074	0.23	328	0.03	2,622	0.20

Table 22: Wood - Secondary Water Resistance Damage

The economic effects for secondary water resistance produced conflicting results as comparted to the numbers of buildings damaged. The Wood - Secondary Water Resistance Economic Results table displays the economic results from this variable change. Residential and commercial categories fared better with secondary water resistance while industrial and all other category types fared worse. The residential category property damage economic loss dropped by over half a million dollars while the commercial category property damage economic loss dropped by almost $20,000. However, the content loss for these two categories were up by over $200,000 and $948 respectively. The reasons behind an increase in the content loss is unclear as the secondary water resistance should actually offer more protection. This could be an issue of a moral hazard where an increased sense of security causes more property to be stored in a manner that increases the chance of damage when the secondary water resistance fails. The property damage economic loss to buildings for all other categories increased by over $14,000 while the content loss of all other categories increasing by over $24,000. The business interruption loss dropped by a total of roughly $114,000 for the residential category, roughly $41,000 for the commercial category, and just over $900 for the others category. The industrial category is the only one that experienced an increase in business interruption loss with a total increase of over $700.

Secondary Water Resistance Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	-$513,660.16	-$19,685.85	$12,956.58	$2,521.79	-$517,867.64
	Content	$226,379.19	$948.25	$20,971.18	$3,979.71	$252,278.33
	Inventory	$0.00	$50.10	$4,594.60	$483.42	$5,128.12
	Subtotal	**-$287,280.97**	**-$18,687.50**	**$38,522.36**	**$6,984.92**	-$260,461.19
Business Interruption Loss						
	Income	-$2,524.32	-$8,595.64	$244.47	-$143.62	-$11,019.11
	Relocation	-$57,454.95	-$3,414.18	$96.99	-$147.71	-$60,919.85
	Rental	-$48,089.37	-$2,903.87	$21.82	-$66.12	-$51,037.54
	Wage	-$5,912.28	-$7,413.44	$409.87	-$564.51	-$13,480.36
	Subtotal	**-$113,980.92**	**-$22,327.13**	**$773.15**	**-$921.96**	-$136,456.86
Total						
	Total	**-$401,261.89**	**-$41,014.63**	**$39,295.51**	**$6,062.96**	**-$396,918.05**

Table 23: Wood - Secondary Water Resistance Economic Results

Secondary water resistance increased the number of buildings that experienced damage from the hurricane by almost 11,000 additional buildings, but reduced the overall costs associated with that damage. Buildings with minor damage increased by 3%, while those with moderate damage increased by almost 7%. The number of buildings destroyed experienced over a 60% increase, but it is not likely that a secondary water resistance led to an increased destruction. It is possible that the replacement costs were increased by having to replace the resistance, although there is not enough information to determine this. A total economic savings of 2.61% was experienced with this variable change. The additional damage to buildings could be caused by damage to the secondary water resistance, which would count as building damage. This would also explain the economic difference between categories as cost would be effected by size and complexity. This indicates that secondary water resistance is not beneficial enough to be added as part of the required elements of the building code.

Roof Shape

The second variable change of roof shape produced beneficial results for the number of buildings damaged and the cost of damage. The Wood - Roof Shape Damage table below displays the results from this variable change. The number of buildings with no damage increased by just under 29,000. The majority of the increase to the no damage category came from minor and moderate damage. These two areas experienced a decrease of roughly 22,000 buildings of the total buildings that shifted to no damage. The number of buildings that received severe damage or that were destroyed dropped by over 6,000 buildings.

Roof Shape Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Wood	28,839	2.15	-10,918	-0.82	-11,759	-0.87	-3,602	-0.26	-2,561	-0.19

Table 24: Wood - Roof Shape Damage

The economic effects for roof shape produced beneficial results for a majority of the categories. The Wood - Roof Shape Economic Results Table below displays the results from this variable change. The residential category experienced a significant decrease in property damage economic expense of over $1.7 million dollars. A bulk of this was in the property damage economic loss for buildings. The commercial category experience and total property damage economic decrease of just over $50,000. The industrial category is the only one that experience a net increase of property damage economic loss with an increase of over $33,800. The business interruption loss was reduced for all categories except for industrial. The residential category experience a reduction of over $250,000, the commercial experienced a reduction in loss of over

$84,000 and the other category experienced a reduction of just over $7,000. The industrial business loss increased by over $34,000.

Roof Shape Economic Results							
Category		**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage							
		Building	-$1,169,746.61	-$37,079.56	$11,879.08	-$5,532.45	-$1,200,479.54
		Content	-$565,613.61	-$14,038.17	$17,822.18	$1,199.47	-$560,630.13
		Inventory	$0.00	-$141.81	$4,149.44	$419.59	$4,427.22
		Subtotal	**-$1,735,360.22**	**-$51,259.54**	**$33,850.70**	**-$3,913.39**	-$1,756,682.45
Business Interruption Loss							
		Income	-$2,516.10	-$11,153.62	$239.19	-$312.16	-$13,742.69
		Relocation	-$173,368.13	-$7,188.71	-$144.08	-$2,213.51	-$182,914.43
		Rental	-$71,168.42	-$4,546.21	$11.90	-$195.75	-$75,898.48
		Wage	-$5,893.16	-$10,225.07	$400.07	-$1,043.94	-$16,762.10
		Subtotal	**-$252,945.81**	**-$33,113.61**	**$507.08**	**-$3,765.36**	-$289,317.70
Total							
		Total	**-$1,988,306.03**	**-$84,373.15**	**$34,357.78**	**-$7,678.75**	**-$2,046,000.15**

Table 25: Wood - Roof Shape Economic Results

Roof Shape produced a reduction in homes destroyed by over 58% and a reduction in homes with severe damage by over 41%. The number of buildings that received no damage increased by 2.5%. The only category which experienced an increase in economic loss was the industrial category which experienced an almost 7.5% increase in economic loss. The economic benefits also produced positive results with a 13.44% total reduction in economic loss. This indicates that a change in the building code would be beneficial. The roof shape for all new buildings or those that are replaced, with the exception of industrial buildings, should be the hip roof shape.

One recurring theme through the analysis is the opposing results of industrial buildings as compared to the other categories. The difference with the industrial loss could be a factor of the size and style of industrial buildings. Other factors could be the interplay of height and width, the vastly more internal open space, the weight of the roof, or the number of buildings with these roof types.

Roof Deck Attachment

The third variable change of roof deck attachment produced beneficial results for the number of buildings damaged and the economic loss for most categories. The Wood - Roof Deck Attachment Damage Table displays these results. The percent of buildings that experienced no damage increased by 7% which resulted in an additional 90,714 buildings with no damage. Buildings with minor to moderate damage accounted for most of this change with a reduction of over 89,000 buildings with minor or moderate damage. The only category to see an increase in building damage was destruction which resulted in a 0.12% increase meaning an additional 1,499 buildings were destroyed.

Roof Deck Attachment Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Wood	90,714	6.76	-63,519	-4.74	-25,914	-1.93	-2,780	-0.20	1,499	0.12

Table 26: Wood - Roof Deck Attachment Damage

The economic effects for roof deck attachment produced beneficial results for a majority of the categories. The Wood - Roof Deck Attachment Economic Results Table below displays the results of this variable change. The residential category experienced a property damage economic loss reduction of over $1.6 million. The property damage content loss for residential increased by just under $12,000. The property damage economic loss for the commercial category had a total reduction of over $31,000. The property damage economic loss for the industrial and all other category increased by just under $38,000. The business interruption loss for all categories decreased. The total decrease for all categories was over $2 million.

Roof Deck Attachment Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	-$1,610,335.51	-$17,534.37	$13,861.50	$1,693.01	-$1,612,315.37
	Content	$11,919.91	-$14,015.23	$18,042.28	$750.66	$16,697.62
	Inventory	$0.00	-$144.24	$4,174.87	$408.85	$4,439.48
	Subtotal	**-$1,598,415.60**	**-$31,693.84**	**$36,078.65**	**$2,852.52**	-$1,591,178.27
Business Interruption Loss						
	Income	-$2,958.94	-$15,295.69	$155.53	-$1,002.58	-$19,101.68
	Relocation	-$267,241.73	-$13,008.17	-$509.53	-$3,937.69	-$284,697.12
	Rental	-$111,646.54	-$8,370.42	-$68.56	-$329.03	-$120,414.55
	Wage	-$6,930.33	-$13,931.03	$265.59	-$2,975.01	-$23,570.78
	Subtotal	**-$388,777.54**	**-$50,605.31**	**-$156.97**	**-$8,244.31**	-$447,784.13
Total						
	Total	**-$1,987,193.14**	**-$82,299.15**	**$35,921.68**	**-$5,391.79**	**-$2,038,962.40**

Table 27: Wood - Roof Deck Attachment Economic Results

The roof deck attachment produced an 8% increase in the number of building with no damage, a 42% decreased in building with minor damage, a 58% decreased in buildings with moderate damage, and a 31% decrease in building with severe damage. The only category that experienced a negative result was the number of buildings destroyed which experienced an increases of 34%. The total economic loss was reduced by more than 13% with this variable change. The only category that experienced an increased loss was the industrial category which experienced a loss increase of 7.83%. This indicates that the roof deck attachment for all new buildings or those that are replaced, with the exception of industrial buildings, should be the 8D@6”/6” attachment.

Roof Wall Connections

The fourth variable change of roof wall connections produced conflicting benefits with regard to the number of buildings damaged. The Wood - Roof Wall Connections Damage Table below displays the results from this variable change. The number of buildings with no damage decreased by almost 11,000. The damage level of these buildings appear to have moved to the minor and moderate damage categories. On the other hand, the number of buildings destroyed dropped by almost 3,000. It appears that these buildings mostly moved into the severe category with the remainder moving into the moderate and minor categories.

Roof-Wall Connections Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Wood	-10,704	-0.80	5,912	0.44	5,607	0.42	1,999	0.15	-2,814	-0.21

Table 28: Wood - Roof Wall Connections Damage

The economic effects for roof wall connections also produced conflicting results as can be seen in the Wood - Roof Wall Connections Economic Results table below. The residential and commercial categories experience a reduction in property damage economic loss. The residential category experienced a reduction of over $640,000 while the commercial category experienced a reduction of roughly $3,000. The industrial and others categories experienced an increase in property damage economic loss with a total increase of over $53,000. The business interruption loss for the residential and commercial categories was reduced by over $51,000 while the industrial and other categories loss increased by over $3,000.

Roof-Wall Connections Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	-$411,939.79	-$778.52	$15,520.11	$8,624.51	-$388,573.69
	Content	-$228,194.96	-$2,258.18	$19,575.10	$4,744.30	-$206,133.74
	Inventory	$0.00	$22.73	$4,399.59	$503.99	$4,926.31
	Subtotal	**-$640,134.75**	**-$3,013.97**	**$39,494.80**	**$13,872.80**	-$589,781.12
Business Interruption Loss						
	Income	-$2,111.68	-$3,527.82	$293.31	$251.88	-$5,094.31
	Relocation	-$14,462.67	$329.95	$282.05	$1,531.68	-$12,318.99
	Rental	-$24,770.83	$58.72	$72.13	$119.07	-$24,520.91
	Wage	-$4,945.65	-$2,298.02	$486.83	$389.37	-$6,367.47
	Subtotal	**-$46,290.83**	**-$5,437.17**	**$1,134.32**	**$2,292.00**	-$48,301.68
Total						
	Total	**-$686,425.58**	**-$8,451.14**	**$40,629.12**	**$16,164.80**	**-$638,082.80**

Table 29: Wood - Roof Wall Connections Economic Results

The roof wall connection produced a reduction in the number of buildings destroyed by almost 65% while producing an increase in minor damage by 3.91%, moderate damage by 12.56%, and severe damage by 22.79%. The economic loss produced a reduction is economic loss of 5.33% for the residential category and 0.5% for the commercial category. The industrial category and others category experienced an increased economic loss of 8.85% and 5.13% respectively. This indicates that the only category that benefits from a mandatory strap for the roof wall connection is the residential category. All other categories would not see an acceptable benefit from this change.

MASONRY

The damage to masonry also follows the typically hurricane pattern with the majority of the damage being experienced on the right side of the storm and at the landfall zone of the hurricane. The map below highlights the damaged caused by Hurricane Hugo and includes all types of damage from minor to destruction. The damage scale moves from green for no damage to red for complete damage.

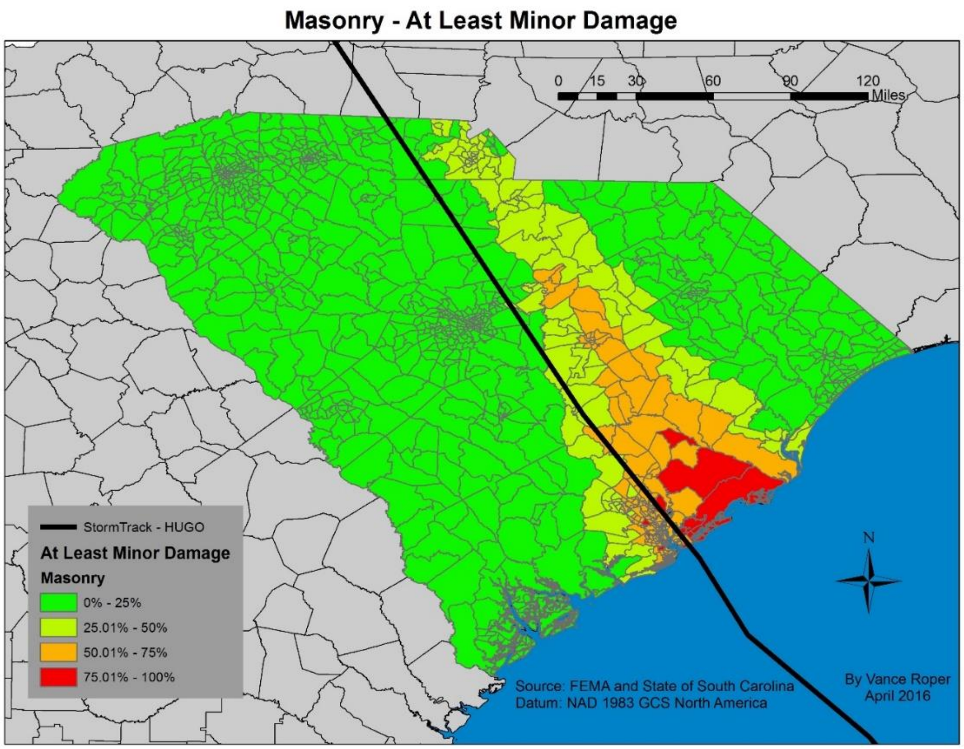


Figure 21: Masonry – At Least Minor Damage

Secondary Water Resistance

The first variable change of secondary water resistance produced negative results across the board with regard to the number of buildings damaged. The Masonry - Secondary Water Resistance table below shows these negative results. The number of houses that experienced no damage dropped by 375. The number with minor to moderate damage increased by 305. The number of buildings with severe damage or that were destroyed increased by 71 buildings.

Secondary Water Resistance Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Masonry	-375	-0.22	205	0.12	100	0.06	15	0.00	56	0.03

Table 30: Masonry - Secondary Water Resistance Damage

The economic effects for secondary water resistance were also negative across the board. The Masonry - Secondary Water Resistance Economic Results table below displays these results. The property damage economic loss for all four categories increased by over $1.1 million. The business interruption loss for all four categories also experienced an increase of over $129,000. This resulted in a total increase across all categories of over $1.244 million.

Secondary Water Resistance Economic Results							
Category		Area	Residential	Commercial	Industrial	Others	Total
Property Damage							
		Building	$672,339.02	$5,599.99	$16,828.52	$8,823.41	$703,590.94
		Content	$373,720.55	$5,547.76	$21,955.55	$5,033.31	$406,257.17
		Inventory	$0.00	$112.62	$4,744.34	$508.49	$5,365.45
		Subtotal	**$1,046,059.57**	**$11,260.37**	**$43,528.41**	**$14,365.21**	$1,115,213.56
Business Interruption Loss							
		Income	-$1,481.18	-$1,990.08	$307.27	$252.04	-$2,911.95
		Relocation	$112,951.36	$782.55	$305.74	$1,542.03	$115,581.68
		Rental	$19,664.52	$409.63	$80.02	$120.21	$20,274.38
		Wage	-$3,468.95	-$994.68	$508.91	$390.38	-$3,564.34
		Subtotal	**$127,665.75**	**-$1,792.58**	**$1,201.94**	**$2,304.66**	$129,379.77
Total							
		Total	**$1,173,725.32**	**$9,467.79**	**$44,730.35**	**$16,669.87**	**$1,244,593.33**

Table 31: Masonry - Secondary Water Resistance Economic Results

Secondary water resistance produced an insignificant change for most categories. The no damage, minor damage, moderate damage and severe damage each experienced roughly a 1% change. The only category that experienced a significant change was the number of buildings destroyed, which increased by over 21%. The economic loss produced an increase of over 8% in total loss. This indicates that secondary water resistance should not be used as a mandatory building code.

Roof Shape

The second variable change of roof shape produced beneficial results across the board. The Masonry - Roof Shape Damage table below highlights these results. The number of buildings that received no damage increased by 1,156. The number of buildings that received minor or moderate damage dropped by almost 1,000. The number of buildings that received severe damage or that were destroyed dropped by over 200.

Roof Shape Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Masonry	1,156	0.68	-455	-0.27	-494	-0.29	-122	-0.08	-84	-0.05

Table 32: Masonry - Roof Shape Damage

The economic effects for roof shape produced mostly negative results which can be seen in the Masonry - Roof Shape Economic Results table below. All four categories experienced an increase in property damage economic loss with this variable change. The combined economic loss for these four categories was more than $1 million. The only category that experienced a reduction in business interruption loss was the commercial category which experienced a reduction of roughly $1,700. The other three categories experienced an increase in business interruption loss of over $130,000.

Roof Shape Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$664,097.34	$5,599.99	$16,828.52	$8,823.41	$695,349.26
	Content	$341,813.43	$5,547.76	$21,955.55	$5,033.31	$374,350.05
	Inventory	$0.00	$112.62	$4,744.34	$508.49	$5,365.45
	Subtotal	**$1,005,910.77**	**$11,260.37**	**$43,528.41**	**$14,365.21**	$1,075,064.76
Business Interruption Loss						
	Income	-$1,481.18	-$1,990.08	$307.27	$252.04	-$2,911.95
	Relocation	$113,247.58	$782.55	$305.74	$1,542.03	$115,877.90
	Rental	$19,553.47	$409.63	$80.02	$120.21	$20,163.33
	Wage	-$3,468.95	-$994.68	$508.91	$390.38	-$3,564.34
	Subtotal	**$127,850.92**	**-$1,792.58**	**$1,201.94**	**$2,304.66**	$129,564.94
Total						
	Total	**$1,133,761.69**	**$9,467.79**	**$44,730.35**	**$16,669.87**	**$1,204,629.70**

Table 33: Masonry - Roof Shape Economic Results

The roof shape variable change produced an increase in no damage of 0.8%, a decreased in minor damage of 3%, a decrease in moderate damage of almost 5%, a decreases in severe damage of almost 6%, and a decrease in the number of buildings destroyed by 32%. However, this variable change produced an across the board increase in the economic loss. The total economic increase was almost 8%, with the residential category experienced an 8.81% increase in the amount of economic loss. This could indicate that the roof shape reduces the chance of a building being damaged while increasing the cost of repair if it is damaged. While the damage results to the buildings produced beneficial results, the total economic loss of over $1.2 million make this change prohibitive. This indicates that the hip roof shape should not be mandated with regard to masonry buildings.

Roof Deck Attachment

The third variable change of roof deck attachment produced mostly beneficial results with building damage. The Masonry - Roof Deck Attachment Damage table below shows that the number of buildings with no damage increased by almost 2,000. The only category that experienced a negative result was the number of buildings that were destroyed which increased by 102 buildings. This represents an increase of 0.06%.

Roof Deck Attachment Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Masonry	1,985	1.16	-1,203	-0.70	-764	-0.45	-120	-0.07	102	0.06

Table 34: Masonry - Roof Deck Attachment Damage

The economic effects for roof deck attachment were almost all negative. As can be seen in the Masonry - Roof Deck Attachment Economic Results table below, all four categories in the property damage economic loss experienced an increase in loss. The total increase in this section was over $1.1 million. The only category that experienced a reduction in business interruption loss was the commercial category which experienced a reduction in loss of just over $2,000. The other three categories experienced a total increase in business interruption loss of over $128,000.

Roof Deck Attachment Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$675,597.21	$5,020.36	$16,828.52	$8,823.41	$706,269.50
	Content	$376,788.47	$5,888.66	$21,955.55	$5,033.31	$409,665.99
	Inventory	$0.00	$139.30	$4,744.34	$508.49	$5,392.13
	Subtotal	**$1,052,385.68**	**$11,048.32**	**$43,528.41**	**$14,365.21**	$1,121,327.62
Business Interruption Loss						
	Income	-$1,481.18	-$2,032.38	$307.27	$252.04	-$2,954.25
	Relocation	$111,019.61	$529.87	$305.74	$1,542.03	$113,397.25
	Rental	$18,745.71	$270.51	$80.02	$120.21	$19,216.45
	Wage	-$3,468.95	-$1,108.03	$508.91	$390.38	-$3,677.69
	Subtotal	**$124,815.19**	**-$2,340.03**	**$1,201.94**	**$2,304.66**	$125,981.76
Total						
	Total	**$1,177,200.87**	**$8,708.29**	**$44,730.35**	**$16,669.87**	**$1,247,309.38**

Table 35: Masonry - Roof Deck Attachment Economic Results

The roof deck attachment produced a beneficial damage result in every category with the exception of destruction. The results ranged from a reduction in damage between 5.7% to 8.11%. The number of buildings destroyed experienced a significant increase of almost 39%. The economic loss increased across the board with this variable change. The total increase in economic loss was 8.19% with the industrial category experiencing the largest increase of 9.75%. This indicates that the economic loss of the roof deck attachment is too great as compared to the building damage numbers. This also indicates that roof deck attachment decreases the likelihood of damage while increasing the cost of repair. The roof deck attachment of 8D@6"/6" for masonry should not be mandated in the building code.

Roof Wall Connections

The fourth variable change of roof wall connection produce mainly negative results. The Masonry - Roof Wall Connection Damage table below shows that most of the categories experienced an increase in damage. Buildings with no damage decreased by 374. Buildings with minor and moderate damage increased by more than 400. Buildings with severe damage increased by 60, but buildings that were destroyed decreased by 105 which would account for the severe damage increase.

Roof-Wall Connection Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Masonry	-374	-0.22	240	0.14	179	0.10	60	0.03	-105	-0.06

Table 36: Masonry - Roof Wall Connection Damage

The economic effects for roof wall connects was almost completely negative. The Masonry - Roof Wall Connections Economic Results Table below displays these negative results. All four categories of property damage economic loss showed an increase in cost. The total increase for these four categories was over $1.13 million. All the categories, with the exception of commercial, experienced an increase in business interruption loss. The commercial category experienced a reduced cost of roughly $2,300 while the other three categories experienced a combined increase in interruption loss of over $143,000.

Roof-Wall Connections Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$708,851.67	$3,338.10	$16,828.52	$8,823.41	$737,841.70
	Content	$357,366.68	$4,023.36	$21,955.55	$5,033.31	$388,378.90
	Inventory	$0.00	$2.46	$4,744.34	$508.49	$5,255.29
	Subtotal	**$1,066,218.35**	**$7,363.92**	**$43,528.41**	**$14,365.21**	$1,131,475.89
Business Interruption Loss						
	Income	-$1,481.18	-$2,039.73	$307.27	$252.04	-$2,961.60
	Relocation	$121,431.29	$568.28	$305.74	$1,542.03	$123,847.34
	Rental	$23,221.07	$234.14	$80.02	$120.21	$23,655.44
	Wage	-$3,468.95	-$1,123.54	$508.91	$390.38	-$3,693.20
	Subtotal	**$139,702.23**	**-$2,360.85**	**$1,201.94**	**$2,304.66**	$140,847.98
Total						
	Total	**$1,205,920.58**	**$5,003.07**	**$44,730.35**	**$16,669.87**	**$1,272,323.87**

Table 37: Masonry - Roof Wall Connections Economic Results

The roof wall connection variable change produced increased damage for each category with the exception of destruction, which experienced a 40% decrease. This decrease amounts to 105 buildings. The economic cost of this variable change produced a total increase in loss of more than 8%, with the industrial category experiencing the largest increase of 9.75%. This indicates that the roof wall connection does not produce enough beneficial results to be a mandated part of the building code.

Shutters

The fifth variable change of shutters produced a beneficial result in each category. The Masonry - Shutter Damage table below displays these changes. The number of buildings that received no damage increased by 6,834. The number of buildings with minor to moderate damage was reduced by over 4,800. The number of building with severe damage was reduced by 1,724 and the number of buildings destroyed was reduced by 245.

Shutter Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Masonry	6,834	3.98	-1,685	-0.98	-3,180	-1.85	-1,724	-1.01	-245	-0.14

Table 38: Masonry - Shutter Damage

The economic effects for the Shutter variable showed mostly beneficial results. The Masonry - Shutter Economic Results table below shows that the only category with an increase in cost was the residential category. This category experienced an increase in property damage economic loss of over $841,000 and an increased in business economic loss of almost $108,000. The three other categories experienced a combined reduction of property damage economic loss of over $371,000. These three categories also experienced a combined reduction in business interruption loss of over $103,000.

Shutter Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$553,081.84	-$109,818.32	-$47,752.07	-$31,796.31	$363,715.14
	Content	$288,380.62	-$86,644.51	-$54,120.42	-$29,340.51	$118,275.18
	Inventory	$0.00	-$1,399.84	-$10,305.83	-$750.29	-$12,455.96
	Subtotal	**$841,462.46**	**-$197,862.67**	**-$112,178.32**	**-$61,887.11**	$469,534.36
Business Interruption Loss						
	Income	-$1,911.66	-$25,264.66	-$848.97	-$433.91	-$28,459.20
	Relocation	$99,344.04	-$23,613.95	-$3,218.57	-$7,892.88	$64,618.64
	Rental	$14,936.22	-$12,164.10	-$525.12	-$623.16	$1,623.84
	Wage	-$4,477.82	-$25,760.94	-$1,391.84	-$1,610.08	-$33,240.68
	Subtotal	**$107,890.78**	**-$86,803.65**	**-$5,984.50**	**-$10,560.03**	$4,542.60
Total						
	Total	**$949,353.24**	**-$284,666.32**	**-$118,162.82**	**-$72,447.14**	**$474,076.96**

Table 39: Masonry - Shutter Economic Results

The shutter variable produced beneficial results across the board with the exception of the residential category. The number of buildings with no damage increased by 4.73%, buildings with minor damage decreased by 11.36%, those with moderate damage decreased by almost 32%, those with severe damage decreased by almost 82%, and the number of buildings destroyed decreased by 93.51%. The economic loss was reduced for the categories of commercial, industrial, and others by 18%, 26%, and 23% respectively. The residential category experienced an increased in economic loss of 7%. This could be due to the replacement cost of shutters and the larger amount of residential properties. This hugely beneficial damage results of this variable change indicates that shutters should be a mandatory item for all new construction and older buildings should be retrofitted with the exception of the residential category.

Masonry Reinforcement

The sixth variable change of masonry reinforcement produced a negative result across the board. The Masonry - Reinforcement Damage table below shows that the number of homes that experienced no damage decreased by 367 buildings. The number of buildings that experienced minor to moderate damage increased by more than 300. The number of buildings that experienced severe damage or were destroyed increased by 56.

Masonry Reinforcement Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Masonry	-367	-0.21	198	0.12	114	0.07	5	0.00	51	0.03

Table 40: Masonry - Reinforcement Damage

The economic effects for the variable change of masonry reinforcement produced mix results which can be seen in the Masonry - Reinforcement Economic Results table below. The residential and commercial categories experienced a total increase in property damage economic loss of over $1.25 million. The categories of industrial and other experienced a combined reduction in property damage economic loss of over $52,000. The business interruption loss of the residential and others category experienced a combined increase in the business interruption loss of roughly $149,000. The two categories of commercial and industrial experienced a combined decrease in business interruption loss of just over $3,000.

Masonry Reinforcement Economic Results							
Category		**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage							
		Building	$759,647.31	$5,594.79	-$19,640.56	$18.88	$745,620.42
		Content	$384,667.43	$5,471.81	-$24,200.54	-$2,366.46	$363,572.24
		Inventory	$0.00	$107.00	-$5,577.94	-$491.89	-$5,962.83
		Subtotal	**$1,144,314.74**	**$11,173.60**	**-$49,419.04**	**-$2,839.47**	$1,103,229.83
Business Interruption Loss							
		Income	-$1,481.18	-$1,990.25	-$346.34	$107.90	-$3,709.87
		Relocation	$127,637.21	$784.87	-$212.41	$930.15	$129,139.82
		Rental	$25,462.15	$409.63	-$92.70	$88.08	$25,867.16
		Wage	-$3,468.95	-$995.08	-$571.35	$333.48	-$4,701.90
		Subtotal	**$148,149.23**	**-$1,790.83**	**-$1,222.80**	**$1,459.61**	$146,595.21
Total							
		Total	**$1,292,463.97**	**$9,382.77**	**-$50,641.84**	**-$1,379.86**	**$1,249,825.04**

Table 41: Masonry - Reinforcement Economic Results

Masonry reinforcement produced increased building damage for all categories. The damage ranged from a low of 0.25% to a high of 19%. The economic results produced an increase of 8% in economic loss. The only category that experienced a reduced economic loss was industrial, which experienced an 11% reduction. The reduction mainly came from content loss. This indicates that masonry reinforcement is not beneficial and should not be a required part of the building code. The industrial businesses might benefit form reinforcement on a case by case basis.

Roof Cover Type

The seventh variable change of roof cover type produced a conflicting set of results for building damage. The Masonry - Roof Cover Damage table below shows that the total number of buildings with no damage decreased by 148. The number of buildings with minor damage dropped by 318 and the number of buildings that were destroyed decreased by 56. The number of buildings with moderate damage decreased by 192 and the number of buildings with severe damage decreased by 34.

Roof Cover Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Masonry	-148	-0.08	318	0.19	-192	-0.11	-34	-0.02	56	0.03

Table 42: Masonry - Roof Cover Damage

The economic effects for the roof cover variable produced mostly negative results. The Masonry - Roof Cover Economic Results table below show that the only category that experienced a decrease in property damage economic loss and business interruption economic loss was the commercial category. This category experienced a reduction of $0.11 and just over $7,400 respectively. The other three categories experienced a total increase in property damage economic loss of more than $1.65

million. These same categories experienced a combined increase of business interruption loss of roughly $146,000.

Roof Cover Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$741,838.37	-$3,601.23	$15,651.92	$6,181.24	$760,070.30
	Content	$382,264.17	$3,513.73	$21,749.43	$4,501.57	$412,028.90
	Inventory	$0.00	$87.39	$4,721.02	$508.49	$5,316.90
	Subtotal	**$1,124,102.54**	**-$0.11**	**$42,122.37**	**$11,191.30**	$1,177,416.10
Business Interruption Loss						
	Income	-$1,558.01	-$3,405.23	$295.30	$70.77	-$4,597.17
	Relocation	$126,379.70	-$835.91	$177.48	$785.06	$126,506.33
	Rental	$23,935.44	-$463.72	$64.11	$46.28	$23,582.11
	Wage	-$3,648.99	-$2,784.31	$490.28	-$53.69	-$5,996.71
	Subtotal	**$145,108.14**	**-$7,489.17**	**$1,027.17**	**$848.42**	$139,494.56
Total						
	Total	**$1,269,210.68**	**-$7,489.28**	**$43,149.54**	**$12,039.72**	**$1,316,910.66**

Table 43: Masonry - Roof Cover Economic Results

The roof cover variable produced mostly negative results. The number of buildings destroyed increased by over 21% while the only reduction in damage came from the moderate and severe categories with each experiencing a reduction of roughly 2%. The total economic loss experienced an increase of more than 8%. This indicates that the roof cover type of BUR should not be mandated as part of the building code.

CONCRETE

The damage to concrete also follows the typically hurricane pattern with the majority of the damage being experienced on the right side of the storm and at the landfall zone of the hurricane. The map below highlights the damaged caused by

Hurricane Hugo and includes all types of damage from minor to destruction. The damage scale moves from green for no damage to red for complete damage.

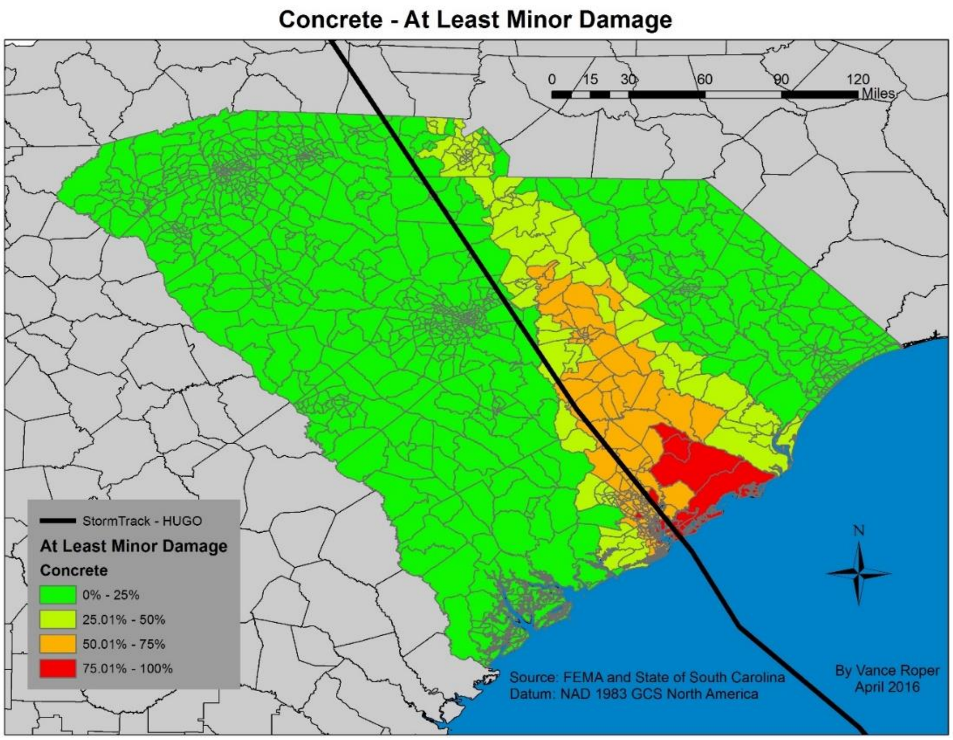


Figure 22: Concrete – At Least Minor Damage

Shutters

The first variable change of shutters produced positive results across the board. The Concrete - Shutter Damage Table below show that buildings with no damage increased by 1,137 which is a 7% increase. Buildings with minor or moderate damage decreased by 861. The number of buildings with severe damage dropped by 267 and there was no change in the number of buildings destroyed.

Shutter Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Concrete	1,137	7.03	-261	-1.62	-610	-3.77	-267	-1.65	0	0.00

Table 44: Concrete - Shutter Damage

The economic effects for the shutter variable produced a mixed result. The Concrete - Shutter Economic Results table below shows that the residential and industrial categories experienced increased property damage economic loss. The combined loss for these two categories was over $1.12 million. The commercial and other categories experienced a reduced property damage economic loss with a combined reduction of over $68,000. The residential category experienced an increase in business interruption loss of over $142,000. The other three categories experienced a combined reduction of business interruption loss of over $35,000.

Shutter Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$741,824.59	-$33,665.68	$1,484.86	-$2,179.34	$707,464.43
	Content	$377,361.50	-$28,371.49	$5,853.90	-$4,301.82	$350,542.09
	Inventory	$0.00	-$424.41	$2,158.13	$486.74	$2,220.46
	Subtotal	**$1,119,186.09**	**-$62,461.58**	**$9,496.89**	**-$5,994.42**	**$1,060,226.98**
Business Interruption Loss						
	Income	-$1,810.70	-$10,612.45	-$3.09	$148.86	-$12,277.38
	Relocation	$125,239.28	-$7,319.34	-$1,268.91	-$1,464.69	$115,186.34
	Rental	$23,340.39	-$3,280.02	-$145.93	-$196.21	$19,718.23
	Wage	-$4,241.19	-$10,850.70	-$1.57	-$268.29	-$15,361.75
	Subtotal	**$142,527.78**	**-$32,062.51**	**-$1,419.50**	**-$1,780.33**	**$107,265.44**
Total						
	Total	**$1,261,713.87**	**-$94,524.09**	**$8,077.39**	**-$7,774.75**	**$1,167,492.42**

Table 45: Concrete - Shutter Economic Results

Shutters on concrete buildings produced positive damage results across the board. The number of buildings with no damage increased by 8.33%, minor damage decreased by 22.58%, moderate damage decreased by 56.12%, and severe damage decreased by over 92%. The economic loss results were conflicting with residential experiencing a 9.8% increase in loss and industrial experiencing a 1.76% increase. The commercial category experienced a 5.97% reduction in loss and the others category experienced a 2.47% decrease in loss. The difference was mainly within the building cost which might indicate that replace cost of shutters was a factor in this difference. The large changes in the building damage indicates that shutters should be a required in the building code for the commercial category but not the other categories.

Roof Cover Type

The second variable change of roof cover type produced mainly beneficial results on a small scale. The Concrete - Roof Cover Type Damage table below shows that the number of buildings with no damage increased by 34. The number of buildings with minor damage increased by 13, but this is likely due to the number of buildings with moderate damage decreasing by 42. The number of buildings with severe damage dropped by 6 and there was no change to the number of buildings destroyed.

Roof Cover Type Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Concrete	34	0.21	13	0.08	-42	-0.26	-6	-0.04	0	0.00

Table 46: Concrete - Roof Cover Type Damage

The economic effects for the roof cover type variable produced almost completely negative results. The Concrete - Roof Cover Type Economic Results table below shows that all four categories experienced an increase in the property damage economic loss with a total increase of over $1.2 million. The only category that experienced a reduced business interruption loss was the commercial category, which experienced a reduction of just over $2,000. The other three categories had a combined increase in the business interruption loss of over $150,000.

Roof Cover Type Economic Results							
Category		**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage							
		Building	$758,951.12	$5,054.14	$16,616.09	$8,682.94	$789,304.29
		Content	$384,584.29	$5,549.75	$21,955.55	$5,033.42	$417,123.01
		Inventory	$0.00	$112.62	$4,744.34	$508.49	$5,365.45
		Subtotal	**$1,143,535.41**	**$10,716.51**	**$43,315.98**	**$14,224.85**	**$1,211,792.75**
Business Interruption Loss							
		Income	-$1,486.50	-$2,075.50	$301.55	$264.19	-$2,996.26
		Relocation	$127,459.52	$637.90	$252.10	$1,516.55	$129,866.07
		Rental	$25,349.55	$401.81	$74.47	$120.15	$25,945.98
		Wage	-$3,481.41	-$1,092.24	$500.48	$450.48	-$3,622.69
		Subtotal	**$147,841.16**	**-$2,128.03**	**$1,128.60**	**$2,351.37**	**$149,193.10**
Total							
		Total	**$1,291,376.57**	**$8,588.48**	**$44,444.58**	**$16,576.22**	**$1,360,985.85**

Table 47: Concrete - Roof Cover Type Economic Results

The roof cover type of BUR produced minimal changes to the building damage with the largest reduction of 3.86% and the largest increase of 1.12%. The economic loss increased across the board with a total increase of 8.94%. This indicates that the roof cover type of BUR should not be mandated in the building codes.

Window Area

The third variable change of window area produced generally beneficial results. The Concrete - Window Area Damage table below show the number of buildings with no damage increased by 81. The number of buildings with minor damage increased by 6, but this is likely do to decreases in other categories. The number of buildings with moderate damage decreased by 27 and the buildings with severe damage decreased by 61. There was no change in the number of buildings destroyed.

Window Area Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Concrete	81	0.50	6	0.03	-27	-0.17	-61	-0.38	0	0.00

Table 48: Concrete - Window Area Damage

The economic effects for the window area variable produced negative results with every category, except the commercial category. The Concrete - Window Area Economic Results table below shows that the commercial category experienced a reduction in property damage economic loss of almost $5,500 and a reduction in business interruption loss of just over $6,000. The other three categories experienced an increased combined property damage economic loss of over nearly $1.2 million and an increased business interruption loss of over $149,000.

Window Area Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$754,801.48	-$2,731.13	$13,968.64	$6,711.96	$772,750.95
	Content	$382,103.45	-$2,736.38	$18,438.20	$3,008.58	$400,813.85
	Inventory	$0.00	-$2.30	$4,175.44	$503.39	$4,676.53
	Subtotal	**$1,136,904.93**	**-$5,469.81**	**$36,582.28**	**$10,223.93**	**$1,178,241.33**
Business Interruption Loss						
	Income	-$1,554.76	-$3,257.02	$251.25	$195.15	-$4,365.38
	Relocation	$127,335.82	-$312.33	$75.44	$923.56	$128,022.49
	Rental	$24,902.45	-$126.60	$39.33	$41.03	$24,856.21
	Wage	-$3,641.41	-$2,545.29	$417.14	$204.64	-$5,564.92
	Subtotal	**$147,042.10**	**-$6,241.24**	**$783.16**	**$1,364.38**	**$142,948.40**
Total						
	Total	**$1,283,947.03**	**-$11,711.05**	**$37,365.44**	**$11,588.31**	**$1,321,189.73**

Table 49: Concrete - Window Area Economic Results

The window area produced beneficial results in the moderate category with a 2.48% reduction and in the severe category with a 21% reduction. The economic loss only decreased in the commercial category with less than a 1% decrease, which was negligible. The highest increase was 9.98% in the residential category and the total economic loss experienced an increase of 8.68%. This indicates that the window area had little effect on the damage results and should not be a mandated part of the building code.

STEEL

The damage to steel also follows the typically hurricane pattern with the majority of the damage being experienced on the right side of the storm and at the landfall zone of the hurricane. The map below highlights the damaged caused by Hurricane Hugo and includes all types of damage from minor to destruction. The damage scale moves from green for no damage to red for complete damage.

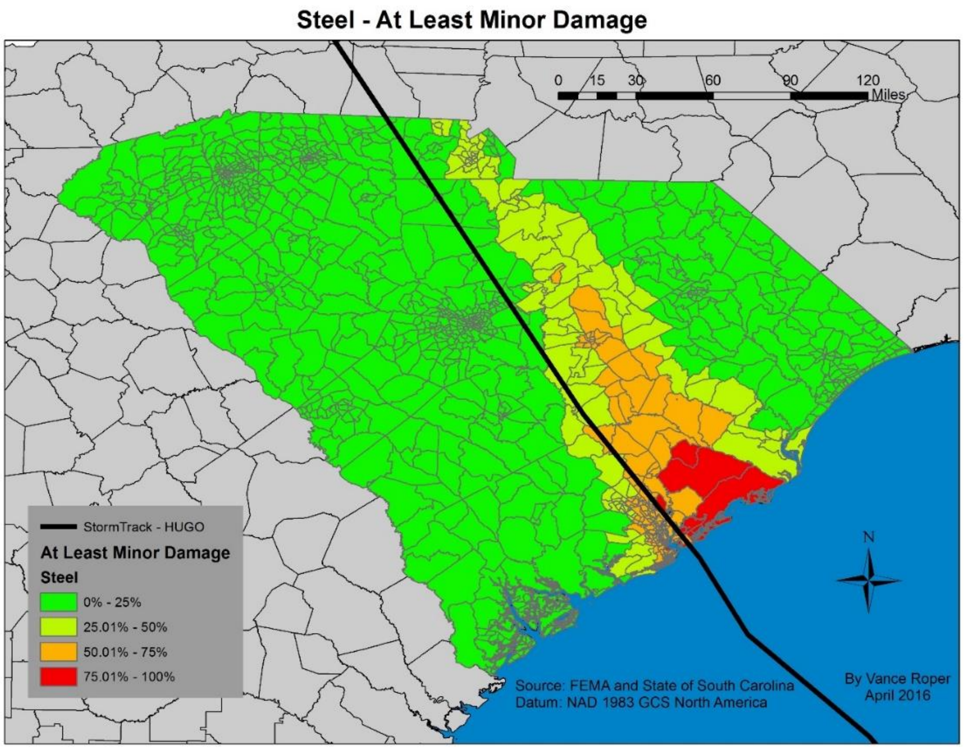


Figure 23: Steel – At Least Minor Damage

Roof Deck Attachment

The first variable change of roof deck attachment produced mixed results. The Steel - Roof Deck Attachment Damage table below shows that the number of buildings with no damage increased by 106. The number of buildings with minor damage did not change and the number with moderate damage increased by 145. The number of buildings with severe damage and that were destroyed were each reduced by 20.

Roof Deck Attachment Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Steel	-106	-0.16	0	0.00	145	0.22	-20	-0.03	-20	-0.03

Table 50: Steel - Roof Deck Attachment Damage

The economic effects for the roof deck attachment variable produced negative results with the exception of the commercial category. The Steel - Roof Deck Attachment Economic Results table below shows these results. The commercial category had a decrease in property damage economic loss of almost $53,000 and a decrease in business interruption loss of just over $7,000. The other three categories experienced a combined increase in the property damage economic loss of nearly $1.2 million. These same categories experienced a combine increased in the business interruption loss of over $150,000. The total economic results indicated an increase in loss of just over $1,287,000

Roof Deck Attachment Economic Results							
Category		**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage							
		Building	$755,788.51	-$28,436.84	$16,619.75	$8,712.83	$752,684.25
		Content	$382,924.25	-$22,504.57	$21,824.23	$4,964.18	$387,208.09
		Inventory	$0.00	-$1,951.86	$4,717.58	$506.30	$3,272.02
		Subtotal	**$1,138,712.76**	**-$52,893.27**	**$43,161.56**	**$14,183.31**	$1,143,164.36
Business Interruption Loss							
		Income	-$1,480.09	-$2,333.88	$305.05	$263.41	-$3,245.51
		Relocation	$127,452.77	-$1,373.08	$312.70	$1,539.66	$127,932.05
		Rental	$25,259.34	-$1,974.52	$79.85	$118.75	$23,483.42
		Wage	-$3,466.40	-$1,665.40	$505.23	$439.64	-$4,186.93
		Subtotal	**$147,765.62**	**-$7,346.88**	**$1,202.83**	**$2,361.46**	$143,983.03
Total							
		Total	**$1,286,478.38**	**-$60,240.15**	**$44,364.39**	**$16,544.77**	**$1,287,147.39**

Table 51: Steel - Roof Deck Attachment Economic Results

The roof deck attachment produced a reduction in damage for the severe category of 1.31% and a reduction in the number of buildings destroyed by almost 59%. The economic loss experienced an increase in all categories except the commercial category which experienced a 3.81% decrease. This indicates that the superior roof deck attachment is only effective in commercial buildings and should be considered on a case by case basis rather than a mandatory building code.

Shutters

The second variable change of shutters produced beneficial damage results in all categories. The Steel - Shutter Damage table below shows that the number of buildings with no damage increased by over 7% to 4,737. The number of buildings with minor damage decreased by 1,201 and those with moderate damage decreased by 2,219. The number of buildings with severe damage decreased by 1,286 and the number of buildings destroyed decreased by 32.

Shutter Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Steel	4,737	7.25	-1,201	-1.83	-2,219	-3.40	-1,286	-1.96	-32	-0.05

Table 52: Steel - Shutter Damage

The economic effects for the shutter variable produced mainly positive results. The Steel - Shutter Economic Results table below shows that the only category which experienced an increase in property damage economic loss and business interruption economic loss was the residential category. The loss increased by $1.1 million and almost $144,000 respectively. The other three categories experienced a combined decrease in the property damage economic loss of over $600,000 and a decrease in business interruption loss of almost $200,000.

Shutter Economic Results							
Category		**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage							
		Building	$741,284.72	-$245,666.09	-$58,964.56	-$25,237.81	$411,416.26
		Content	$377,121.65	-$200,228.25	-$56,371.82	-$22,864.47	$97,657.11
		Inventory	$0.00	-$7,622.56	-$7,211.31	$182.30	-$14,651.57
		Subtotal	**$1,118,406.37**	**-$453,516.90**	**-$122,547.69**	**-$47,919.98**	$494,421.80
Business Interruption Loss							
		Income	-$1,744.11	-$51,559.80	-$987.51	-$197.81	-$54,489.23
		Relocation	$125,914.26	-$44,171.49	-$7,635.07	-$7,703.31	$66,404.39
		Rental	$23,804.55	-$22,716.89	-$975.33	-$969.63	-$857.30
		Wage	-$4,085.36	-$51,994.24	-$1,586.87	-$2,238.99	-$59,905.46
		Subtotal	**$143,889.34**	**-$170,442.42**	**-$11,184.78**	**-$11,109.74**	-$48,847.60
Total							
		Total	**$1,262,295.71**	**-$623,959.32**	**-$133,732.47**	**-$59,029.72**	**$445,574.20**

Table 53: Steel - Shutter Economic Results

Shutters produced positive results across the board with regard to building damage. The number of buildings destroyed was reduced by 94%, severe damage was reduced by 84%, moderate damage was reduced by 61%, minor damage was reduced by 30%, and buildings with no damage increased by 8%. The economic loss was reduced by 39% for commercial, 29% for industrial, and 19% for others. The only category that experienced an increase in economic loss was residential with a 9.81% increase. As in other categories for shutters, this could be due to the larger amount of residential buildings and the replacement costs of shutters. This indicates that shutters should be mandated as part of the building code for all new construction and current buildings should be retrofitted with the exception of the residential category.

Roof Cover Type

The third variable change of roof cover type produced manly beneficial results. The Steel - Roof Cover Type Damage table below shows that the number of buildings with no damage increased by 106. The number of buildings with minor damage increased by 31 which is likely do to decreases in other categories. The number of buildings with moderate damage decreased by 108 and the number of buildings with severe damage decreased by 29. The number of buildings that were destroyed did not change.

Roof Cover Type Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Steel	106	0.16	31	0.05	-108	-0.17	-29	-0.04	0	0.00

Table 54: Steel - Roof Cover Type Damage

The economic effects for the roof cover type variable produced negative results for every category except the commercial category. The Steel - Roof Cover Type Economic Results table below shows the results for this variable run. The commercial category experienced a reduction in property damage economic loss of just over $3,800 and a reduction in business interruption loss of almost $11,000. The other three categories experienced a combined increase in property damage economic loss of nearly $1.2 million. These same categories experienced a combined increase in business interruption loss of just over $148,000.

Roof Cover Type Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$756,091.36	-$6,780.77	$11,936.53	$6,647.19	$767,894.31
	Content	$384,114.27	$2,847.83	$20,903.52	$4,643.50	$412,509.12
	Inventory	$0.00	$71.95	$4,580.48	$502.65	$5,155.08
	Subtotal	**$1,140,205.63**	**-$3,860.99**	**$37,420.53**	**$11,793.34**	$1,185,558.51
Business Interruption Loss						
	Income	-$1,556.91	-$4,958.78	$232.43	$126.32	-$6,156.94
	Relocation	$127,499.81	-$1,264.64	-$75.94	$740.60	$126,899.83
	Rental	$24,960.41	-$701.17	$16.72	$14.08	$24,290.04
	Wage	-$3,646.40	-$4,007.59	$389.05	$124.87	-$7,140.07
	Subtotal	**$147,256.91**	**-$10,932.18**	**$562.26**	**$1,005.87**	$137,892.86
Total						
	Total	**$1,287,462.54**	**-$14,793.17**	**$37,982.79**	**$12,799.21**	**$1,323,451.37**

Table 55: Steel - Roof Cover Type Economic Results

The roof cover type of BUR had mixed results with moderate category experiencing a reduction of 3% and the severe category experiencing a 2% reduction. The minor category experienced a 1% increase. The economic loss produced an increase in the residential category of 10%, an increase of 8% in the industrial category, and an increase of 4% in the commercial category. A reduction of 1% was a negligible result for the commercial category. This indicates that the roof cover type does not have a major effect and should not be a mandated part of the code.

Window area

The fourth variable change of window produced beneficial damage results. The Steel - Window Area Damage table below shows that the number of buildings with no damage increased by 300. The number of moderate damage buildings decreased by 92, the number of severe damage buildings decreased by 215, and there was no change in the number of buildings destroyed. The only category that had negative results was the minor damage buildings which experienced an increase of 7, which was likely caused by the decreases of the other categories.

Window Area Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
Steel	300	0.46	7	0.01	-92	-0.14	-215	-0.32	0	0.00

Table 56: Steel - Window Area Damage

The economic effects for the window variable produced mainly negative results. The Steel - Window Area Economic Results table below shows that the commercial category was the only one that had beneficial results. This category experienced a decrease of over $58,000 in property damage economic loss and a reduction of almost $30,000 in business interruption loss. The other three categories experienced a combined increase in property damage economic loss of more than $1.1 million and a combined increase in business economic loss of just over $148,000.

Window Area Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$756,977.34	-$29,212.37	$2,371.53	$2,469.08	$732,605.58
	Content	$383,148.31	-$28,867.38	$4,608.16	-$1,085.11	$357,803.98
	Inventory	$0.00	-$552.93	$2,083.38	$437.02	$1,967.47
	Subtotal	**$1,140,125.65**	**-$58,632.68**	**$9,063.07**	**$1,820.99**	$1,092,377.03
Business Interruption Loss						
	Income	-$1,534.16	-$11,412.26	$83.93	$156.54	-$12,705.95
	Relocation	$127,484.98	-$4,775.51	-$732.79	-$49.53	$121,927.15
	Rental	$25,257.78	-$2,885.74	-$97.19	-$95.73	$22,179.12
	Wage	-$3,593.18	-$10,547.74	$145.80	-$144.23	-$14,139.35
	Subtotal	**$147,615.42**	**-$29,621.25**	**-$600.25**	**-$132.95**	$117,260.97
Total						
	Total	**$1,287,741.07**	**-$88,253.93**	**$8,462.82**	**$1,688.04**	**$1,209,638.00**

Table 57: Steel - Window Area Economic Results

The window area variable only produced significant changes in the severe damage category with a 14% reduction. All categories, with the exception of commercial, experienced an increase in economic loss with residential experiencing the largest increase of 10%. This could be caused by commercial buildings having more windows than the other building categories, resulting in a greater effect for this category. This indicates that the window area does not produce beneficial effects for steel buildings and should not be a mandated part of the building code.

MANUFACTURED HOME

The damage to manufactured homes also follows the typically hurricane pattern with the majority of the damage being experienced on the right side of the storm and at the landfall zone of the hurricane. The map below highlights the damaged caused by

Hurricane Hugo and includes all types of damage from minor to destruction. The damage scale moves from green for no damage to red for complete damage.

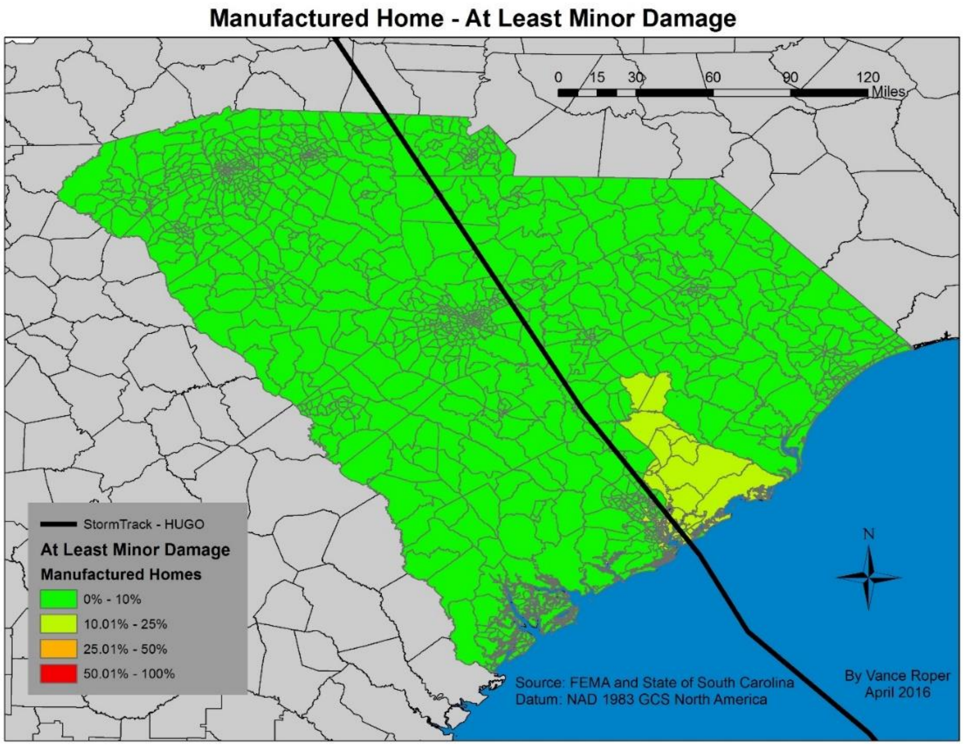


Figure 24: Manufactured Home – At Least Minor Damage

Shutters

The first variable change of shutters produced beneficial damage results across the board. The Manufactured Home - Shutters Damage table below shows that the number of buildings with no damage increased by 1,127. The number of buildings with minor and moderate damage decreased by 333 and 131 respectively. The number of buildings with severe damage decreased by 39 and the number of buildings destroyed dropped by 624.

Shutter Damage										
Building Type	**None**		**Minor**		**Moderate**		**Severe**		**Destruction**	
	Count	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
MH	1,127	0.30	-333	-0.09	-131	-0.03	-39	-0.01	-624	-0.16

Table 58: Manufactured Home - Shutter Damage

The economic effects for the shutter variable produced almost completely negative results. The Manufactured Home - Shutter Economic Results table below shows that all four categories experienced a combined property damage loss of almost $1.1 million. The categories of residential, industrial, and other experienced a combined business interruption loss of more than $140,000. The commercial category experienced a reduction in business interruption loss of almost $1,800.

Shutter Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$679,137.82	$5,599.99	$16,828.52	$8,823.41	$710,389.74
	Content	$345,103.00	$5,547.76	$21,955.55	$5,033.31	$377,639.62
	Inventory	$0.00	$112.62	$4,744.34	$508.49	$5,365.45
	Subtotal	**$1,024,240.82**	**$11,260.37**	**$43,528.41**	**$14,365.21**	$1,093,394.81
Business Interruption Loss						
	Income	-$1,481.18	-$1,990.08	$307.27	$252.04	-$2,911.95
	Relocation	$118,186.29	$782.55	$305.74	$1,542.03	$120,816.61
	Rental	$24,254.43	$409.63	$80.02	$120.21	$24,864.29
	Wage	-$3,468.95	-$994.68	$508.91	$390.38	-$3,564.34
	Subtotal	**$137,490.59**	**-$1,792.58**	**$1,201.94**	**$2,304.66**	**$139,204.61**
Total						
	Total	**$1,161,731.41**	**$9,467.79**	**$44,730.35**	**$16,669.87**	**$1,232,599.42**

Table 59: Manufactured Home - Shutter Economic Results

Shutters produced a beneficial effect across all damage categories. Minor damage was reduced by 14%, moderate damage was reduced by 7%, severe damage was reduced by 19%, and destruction was reduced by 75%. The economic loss showed a total increase of 8% with the largest increase coming from the industrial category at 9.75%. The large beneficial changes in building damage and destruction, combined with the increase in economic loss, indicates that shutters should be a consideration for all categories on a case by case basis.

Tie-downs

The second variable change of tie-downs produced beneficial results across the board. The Manufactured Home - Tie Down Damage table below shows that the number of buildings with no damage increased by 124. The number of buildings with minor damage decreased by 80 and the number of buildings with moderate damage decreased by 100. The number of buildings with severe damage decreased by 126 and the number of buildings that were destroyed decreased by 18

Tie Down Damage										
Building Type	None		Minor		Moderate		Severe		Destruction	
	Count	(%)	Count	(%)	Count	(%)	Count	(%)	Count	(%)
MH	124	0.03	-80	-0.03	100	0.03	-126	-0.03	-18	-0.01

Table 60: Manufactured Home - Tie Down Damage

The economic effects for the tie-down variable produced almost completely negative results. The Manufactured Home - Tie Down Economic Results table below shows the results from this variable change. All four categories had a combined increase in property damage loss of more than $1.5 million. The only category that experienced a reduced business interruption loss was the commercial category with a reduction of almost $1,800. The other three categories had a combined increase in business interruption loss of more than $146,000.

Tie Down Economic Results						
Category	**Area**	**Residential**	**Commercial**	**Industrial**	**Others**	**Total**
Property Damage						
	Building	$724,403.66	$5,599.99	$16,828.52	$8,823.41	$755,655.58
	Content	$363,963.15	$5,547.76	$21,955.55	$5,033.31	$396,499.77
	Inventory	$0.00	$112.62	$4,744.34	$508.49	$5,365.45
	Subtotal	**$1,088,366.81**	**$11,260.37**	**$43,528.41**	**$14,365.21**	**$1,157,520.80**
Business Interruption Loss						
	Income	-$1,481.18	-$1,990.08	$307.27	$252.04	-$2,911.95
	Relocation	$123,954.94	$782.55	$305.74	$1,542.03	$126,585.26
	Rental	$24,835.46	$409.63	$80.02	$120.21	$25,445.32
	Wage	-$3,468.95	-$994.68	$508.91	$390.38	-$3,564.34
	Subtotal	**$143,840.27**	**-$1,792.58**	**$1,201.94**	**$2,304.66**	**$145,554.29**
Total						
	Total	**$1,232,207.08**	**$9,467.79**	**$44,730.35**	**$16,669.87**	**$1,303,075.09**

Table 61: Manufactured Home - Tie Down Economic Results

The tie-down variable had positive damage results in every category except for moderate damage, which experienced a 5% increase. The severe category experienced a 61% decrease in the number of buildings with severe damage. The economic loss showed a total increase in economic loss of 8.56%. The commercial category experienced the lowest increase with a 0.6% economic loss increase. This indicates that the tie-down variable does not have a large enough effect on manufactured homes to be considered as a mandatory building code, but should considered on a case by case basis.

Variable Result Overview					
Variables	**Building Categories**				
	Wood	**Masonry**	**Concrete**	**Steel**	**Manufactured**
Secondary Water Resistance	No	No	---	---	---
Roof Shape	Yes (Except Industrial)	No	---	---	---
Roof Deck Attachment	Yes (Except Industrial)	No	---	Commercial Only	---
Roof Wall Connections	Residential Only	No	---	---	---
Shutters	---	Yes (Except Residential)	Commercial Only	Yes (Except Residential)	Case by Case
Reinforcement	---	Industrial Only	---	---	---
Roof Cover	---	No	No	No	---
Window Area	---	---	No	No	---
Tie Down	---	---	---	---	Commercial Only

Table 62: Variable Result Overview

ECONOMIC RESULTS

The effect of the changes discussed above will have economic benefits to the state of South Carolina and to individuals. The savings in costs from areas such as damage repair, loss of income, and relocation can be significant. According to the buildings stock for South Carolina, there are 1,833,420 residential buildings, 91,921 commercial buildings, and 26,568 industrial buildings (Federal Emergency Management Agency, HAZUS, 2015). The economic benefits described in the results above are based on these numbers. These benefits will increase as the population grows within the state. As such, populations projections can be used to estimate the future cost savings if the proposed changes were made.

According to the State of South Carolina, the projected population growth from a 2010 baseline will be a ten percent increase for the year 2020, a fifteen percent increase for 2025 and a twenty percent increase for 2030 (State of South Carolina, Status of Population Projections, 2010). This means that the population will growth by five percent every five years. The potential savings can be calculated using the current economic benefits and the population growth. These benefits can be seen in the Projected Economic Benefits table below. The chart lists the total benefits for each of the five categories of wood, masonry, concrete, steel, and manufactured homes. Manufactured home recommendations for all three categories of residential, commercial, and industrial are on a case by case basis so the economic values are not contained in the chart.

Projected Economic Benefits			
Building Categories	**Economic Categories**		
	Residential	Commercial	Industrial
Wood	**2020** $466,192.48 **2025** $699,288.71 **2030** $932,384.95	**2020** $16,667.23 **2025** $25,000.85 **2030** $33,334.46	---
Masonry	---	**2020** $14,233.32 **2025** $28,466.63 **2030** $42,699.95	**2020** $16,880.47 **2025** $25,320.70 **2030** $33,760.93
Concrete	---	**2020** $9,452.41 **2025** $14,178.61 **2030** $18,904.82	---
Steel	---	**2020** $68,419.95 **2025** $102,629.92 **2030** $136,839.89	**2020** $13,373.25 **2025** $20,059.87 **2030** $26,746.49
Manufactured Home	---	---	---

Table 63: Projected Economic Benefits

POLITICAL FEASIBILITY

Each recommendation for the building codes were based on the benefits derived from the model of the variable changes. However, the political feasibility of these changes should be taken into account. For example, the roof type needs to include the preference of those who own the property. It may not be appropriate for the government to delve so deep into the design of induvial property owner's homes.

Furthermore, items such as window area have benefits beyond protection. Many people would not like to work in dark and enclosed buildings. Companies may be willing to pay the costs of damage caused by storms in order to improve employee satisfaction or to attract talent.

Many option exist to deal with these competing notions. One such way is to allow individuals or companies the choice of which building options they would like. With this option, it would be paramount to provide all the information about the benefits and costs with the associated building options. This would have the advantage of providing transparency on building options and their respective benefits, while at the same time presenting the costs of those items.

This option would require protections being put into place to protect the taxpayer from having to cover the costs of decisions made by individuals and companies. One way to handle this is to connect taxpayer recovery options to building choices. For example, if an individual or company goes with a less resilient option, then they would have less access to taxpayer based recovery funds. Another option is to incentivize more resilient options to increase its use. The incentives could be provided to individuals, companies, and insurance agencies.

CONCLUSION

The various model runs with building code changes produced a mixture of beneficial results, negative results, and results that provided no real change. Many of the variable changes had different affects across the categories of wood, masonry, concrete, steel, and manufactured homes. The Variable Result Overview table below provides a quick breakdown of whether the variables should be a mandated part of the building code.

WOOD

The wood category produced beneficial results in many of the model runs. The first variable of secondary water resistance did not provide enough benefits to be a required element of the building code. The second variable of roof shape produced highly beneficial results indicating that all new buildings or those that are replaced, with the exception of industrial buildings, should use the hip roof shape. The third variable change of roof deck attachment with the 8D@6”/6” attachment should be used for all new buildings or those that are replaced, with the exception of industrial buildings. The last variable change of roof wall connection only provided an acceptable benefit to residential buildings and should only be a required component for that building type.

MASONRY

The masonry category did not experience many benefits from the variable changes. The secondary water resistance variable change produced an insignificant change for most categories and should not be used as a mandatory building code. The second variable change of roof shape to all hip shape produced negative results and should not be mandated with regard to masonry buildings. The third variable change of roof deck attachment also produced negative benefits which means that it should not be mandated as part of the building code. The next variable change of roof wall connection did not produce enough beneficial results to be a mandated part of the building code. The fifth variable change of shutters produced beneficial results across the board with the exception of the residential category. The results of this variable change indicates that shutters should be a mandatory item for all new construction and older buildings should be retrofitted with the exception of residential structures. The sixth variable change of masonry reinforcement is not recommended for a mandated building code change, but should be considered for the industrial category on a case by case basis. The last variable change of roof cover type to all BUR did not produce beneficial results and should not be mandated as part of the building code.

CONCRETE

The concrete category only experienced one beneficial result from the variable changes. The variable change of shutters on concrete buildings produced positive results for the commercial category and should be mandated for that category. Neither the roof cover variable change or the window area variable change produced beneficial results and neither should be a mandated part of the building code.

STEEL

The steel category had a mixture of results for the variable changes. The first variable change of roof deck attachment is only effective in commercial buildings and should be considered on a case by case basis rather than a mandatory building code. The second variable change of shutters was beneficial across most categories and should be mandated as part of the building code for all new construction and current buildings should be retrofitted, with the exception of the residential category. The third variable change of roof cover type had no major effect and should not be a mandated part of the code. The last variable of window area did not produce beneficial effects for steel buildings and should not be mandated for the building code.

MANUFACTURED HOMES

The final category of manufactured homes had one beneficial result and on mixed result. The shutter variable change produced a beneficial effect across all damage categories and indicates that shutters should be a consideration for all categories on a case by case basis. The tie-down variable does not have a large effect on manufactured homes, which means it should not be a mandatory building code but should be considered on a case by case basis. It is possible that the tie-downs had a large effect on older manufactured homes. The effect of this would be hard to detect because as each year passes, fewer pre-1994 homes remain in existence. This would produce low results even if the effects have been beneficial.

Some of the results produced unexpected effects. An examples of this would be increased destruction of homes with secondary water resistance. It is not likely that these unexpected effects would hold up under intense scrutiny. It could be a quirk in the data or in the computer code. While this paper did not venture into those areas, it would be beneficial to review those aspects in future research.

SPATIAL EFFECT

The spatial effect of the buildings location does have an effect on the damage. The closer a structure is to the path of the hurricane the more likely the structure will be damaged. This makes logical sense as the storm path dictates where the brunt of the storms force will occur. The location of building categories (wood, masonry, concrete, steel, and manufactured homes) throughout the state seem to be similarly situated. It does not appear that any one category has more prominence along the storm path. This means that the likelihood of building category disbursement having an effect on the results is low.

ECONOMIC SAVINGS

The recommended changes produce economic savings to both the state and the residents within the state. The population is projected to grow at a pace of five percent every five years. This means that changes to the building code would produce greater effects as times passes. While these benefits vary by building type and potential future storm paths, the savings are significant thereby making the changes useful.

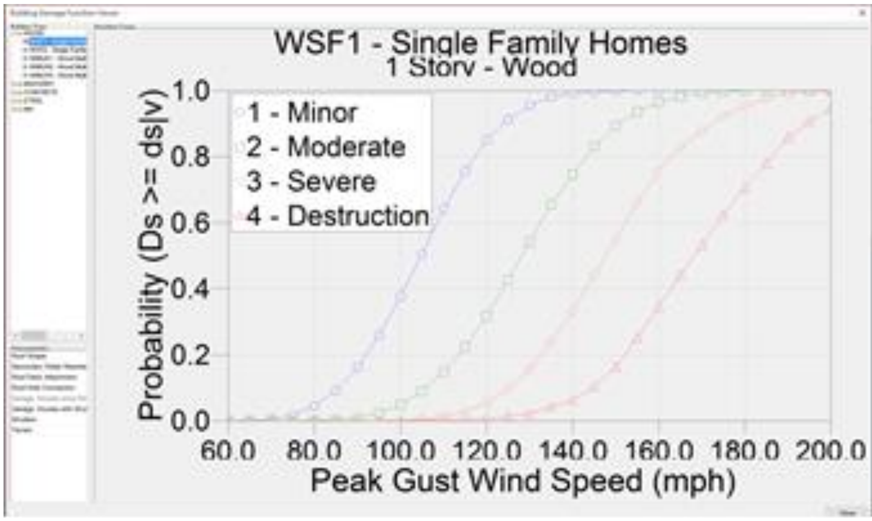
POLITICAL FEASIBILITY

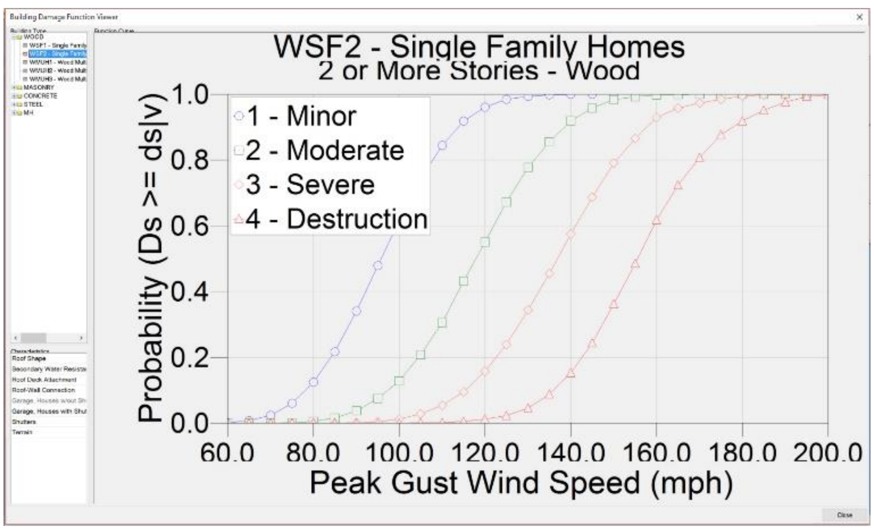
While many options were recommended based on the modeling, not all of these options are politically feasible nor politically advisable. Americans pride themselves on the freedom to make individual choices. As such, each recommendation needs to take this into account with regard to mandating parts of the building code. The best way to approach this is a dialog between the community and its political leaders to determine the best path for each city, county, region, and state.

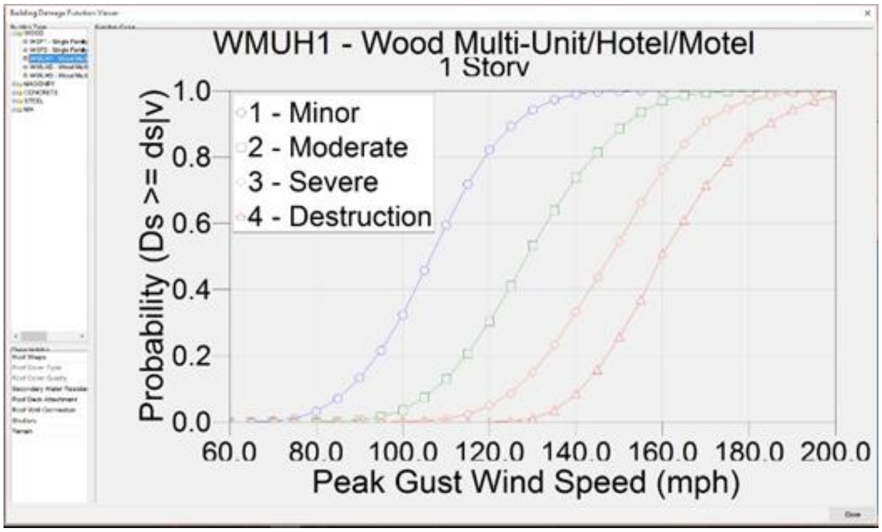
FUTURE RESEARCH

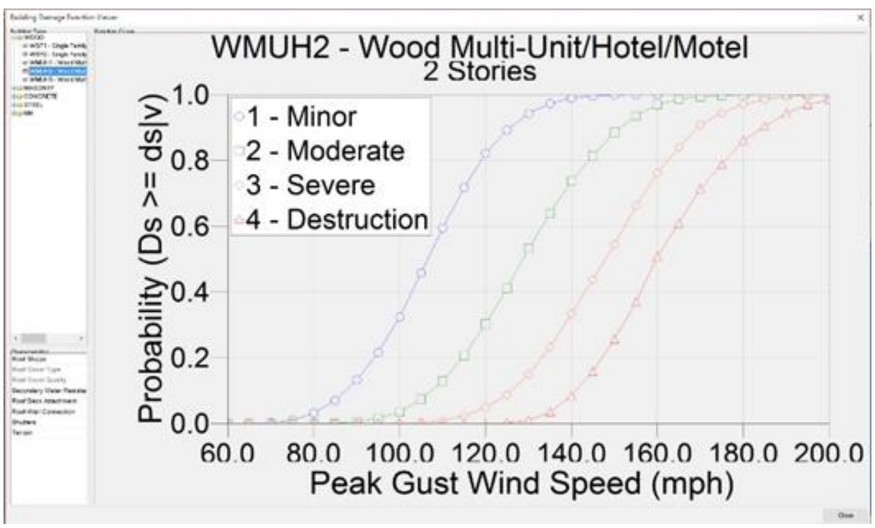
Overall, this research study produced useable results for all five categories of building types. This research could be expanded upon by using a probabilistic hurricane model with varying hurricane strength. This could help produce tables which can explain the upper levels of protection of each building code change. Further research could examine potential code glitches that might produce unlikely results, some of which were seen during the study. Future research could also look at an expansion of the quantitative analysis to include the building costs of each item. Ultimately, this research model could also be applied to other geographic areas in order to facilitate a metadata project once enough areas have been researched.

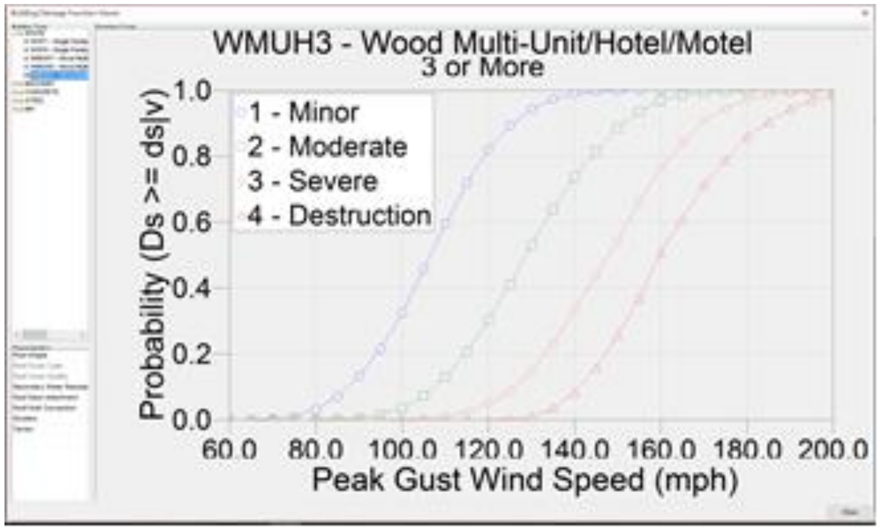
Appendix 1 Wood Damage Curves



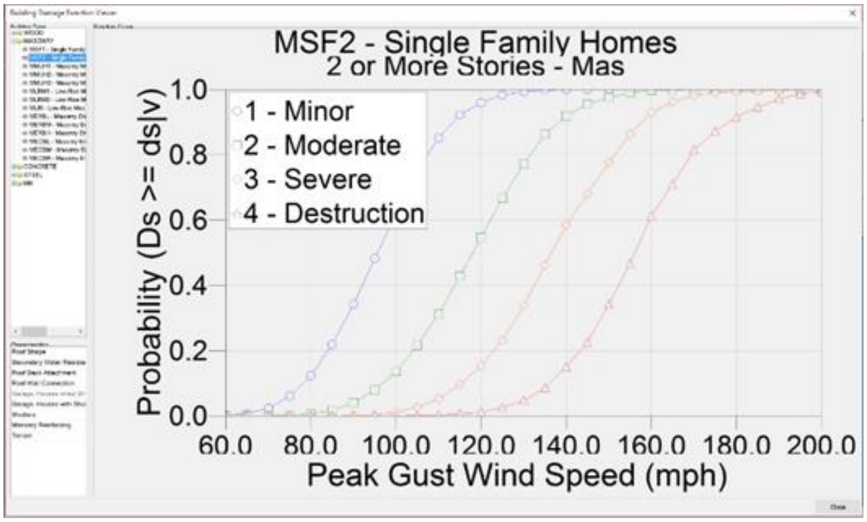


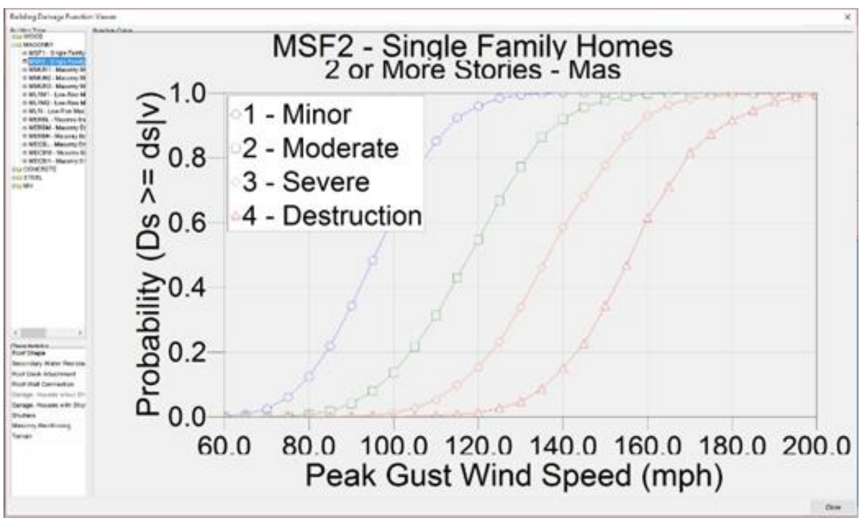

WMUH1 - Wood Multi-Unit/Hotel/Motel
1 Story
Probability (Ds >= ds|v)
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
0.0
0.2
0.4
0.6
0.8
1.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

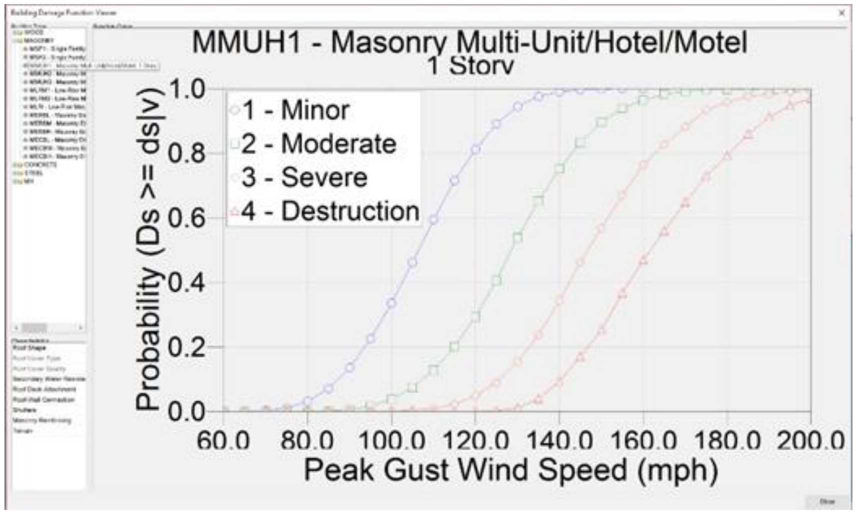

WMUH2 - Wood Multi-Unit/Hotel/Motel
2 Stories
Probability (Ds >= ds|v)
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
0.0
0.2
0.4
0.6
0.8
1.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

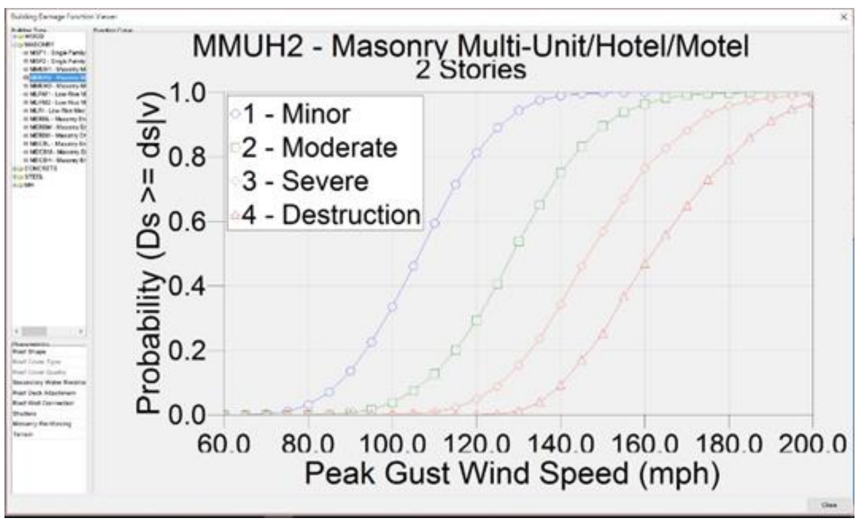

WMUH3 - Wood Multi-Unit/Hotel/Motel
3 or More
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

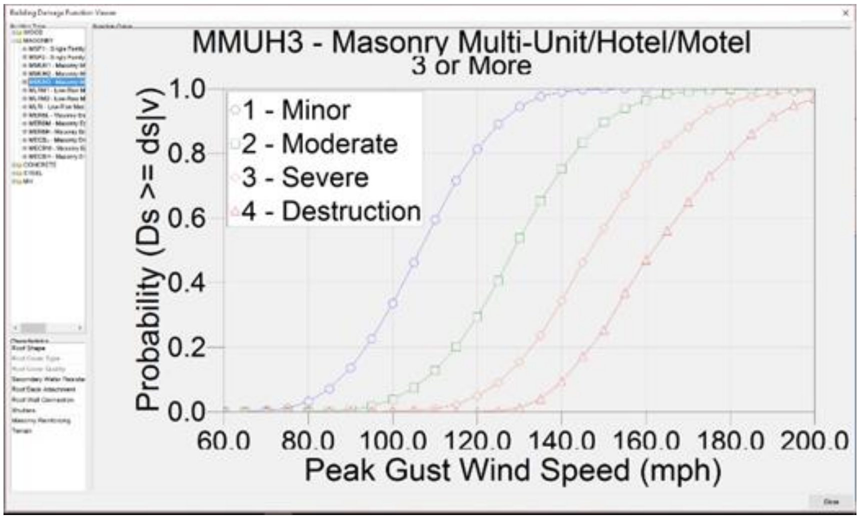
Appendix 2 Masonry Damage Curves

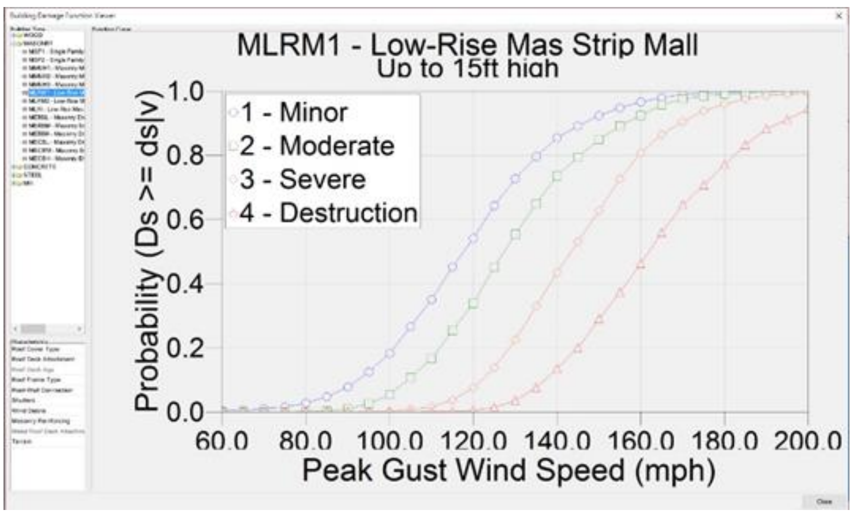


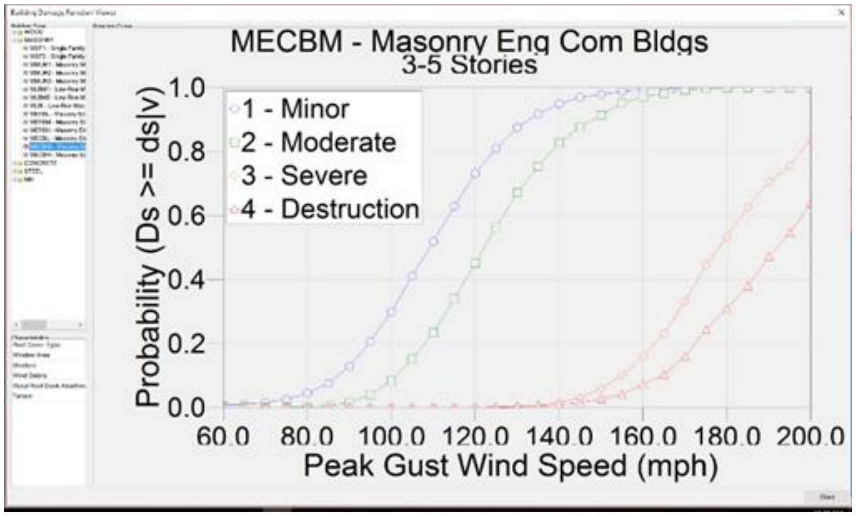


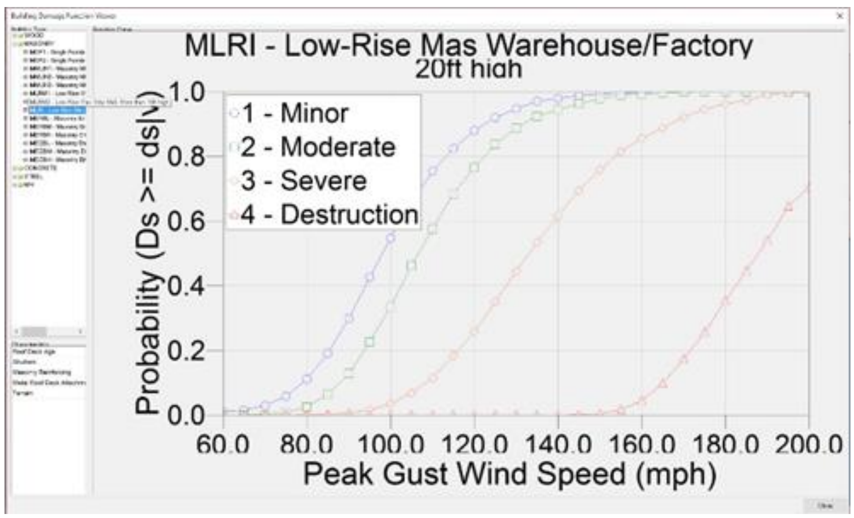

MMUH1 - Masonry Multi-Unit/Hotel/Motel
1 Story
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

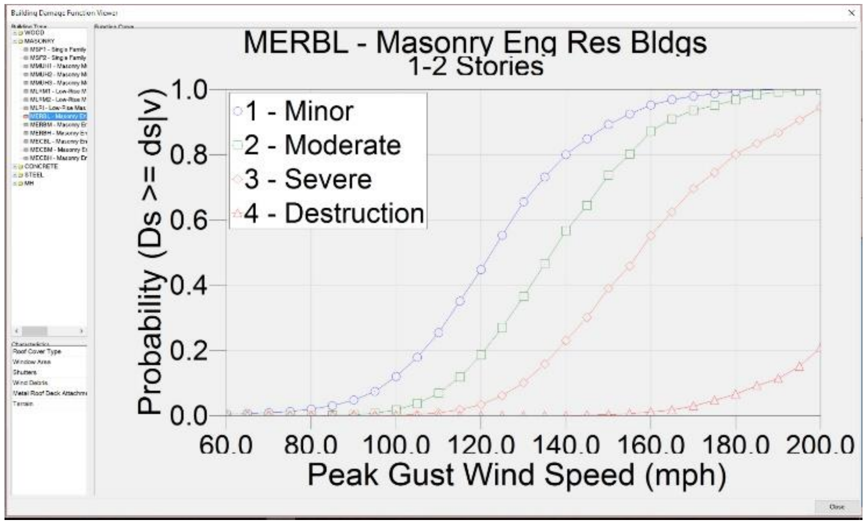

MMUH2 - Masonry Multi-Unit/Hotel/Motel
2 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

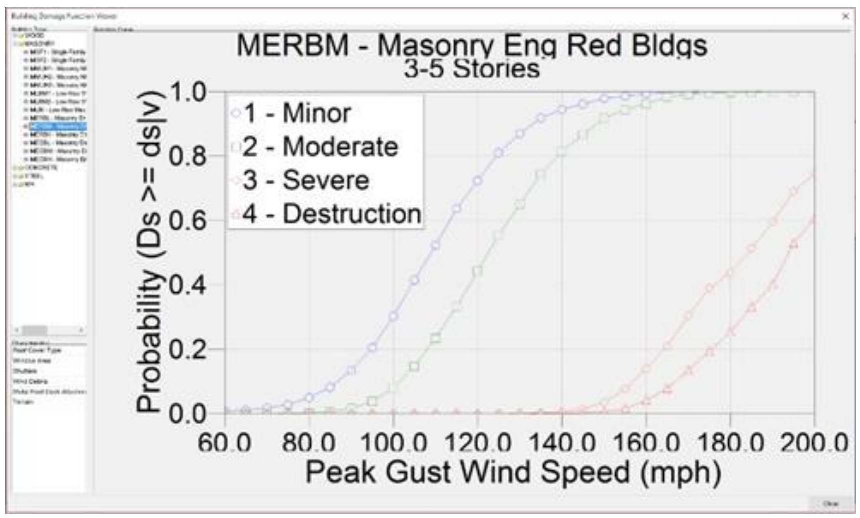

MMUH3 - Masonry Multi-Unit/Hotel/Motel
3 or More
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

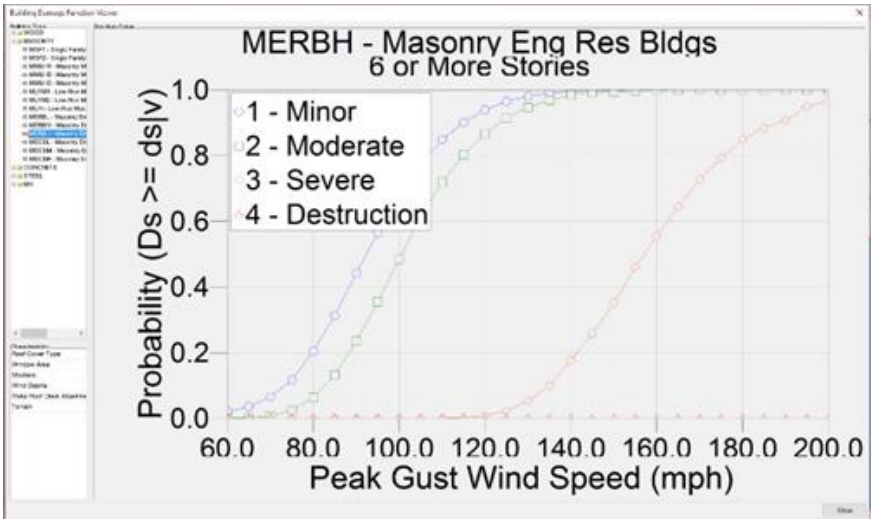

MLRM1 - Low-Rise Mas Strip Mall
Up to 15ft high
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

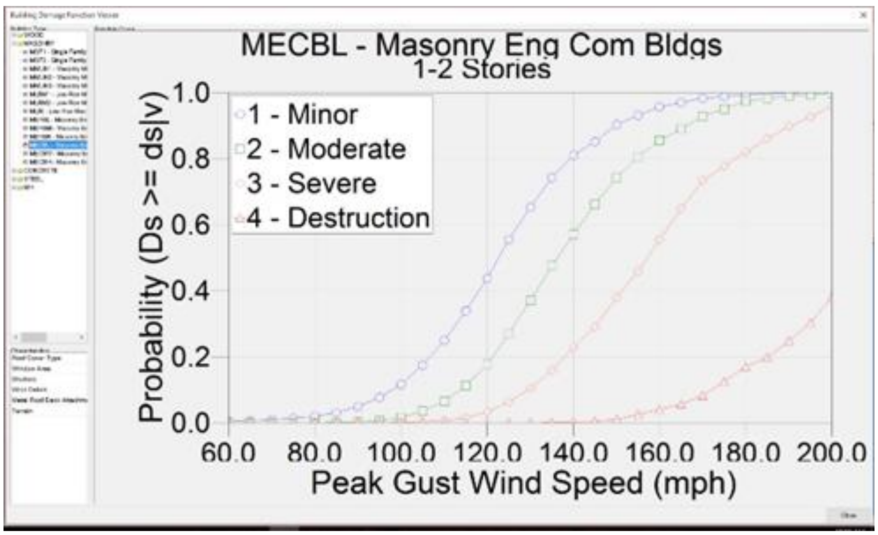

MECBM - Masonry Eng Com Bldgs
3-5 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

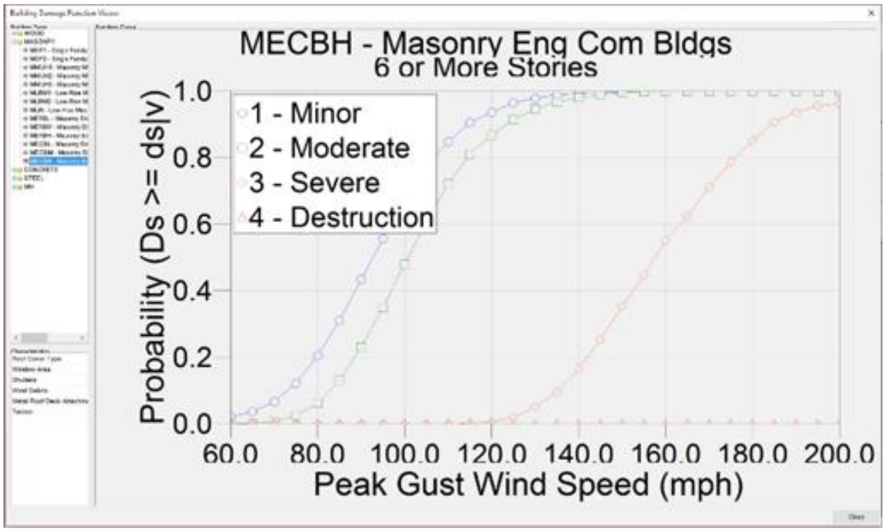

MLRI - Low-Rise Mas Warehouse/Factory
20ft high
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)


MERBL - Masonry Eng Res Bldgs
1-2 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

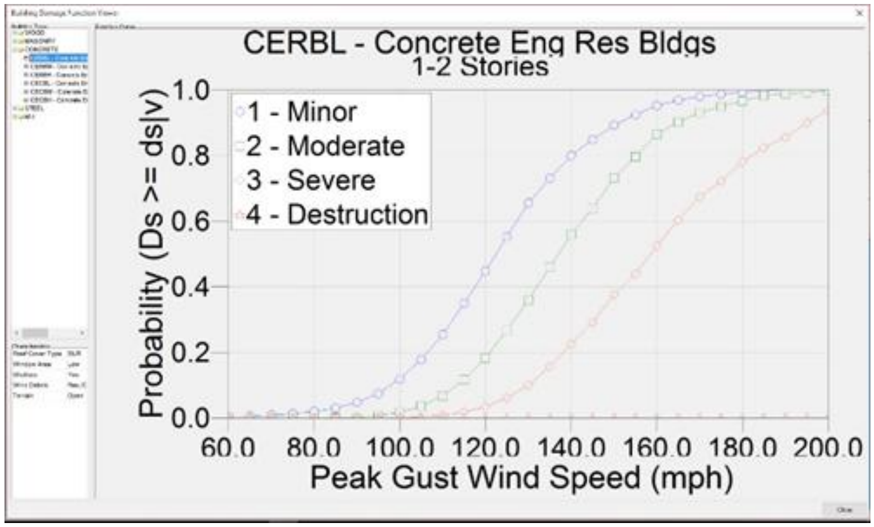

MERBM - Masonry Eng Red Bldgs
3-5 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

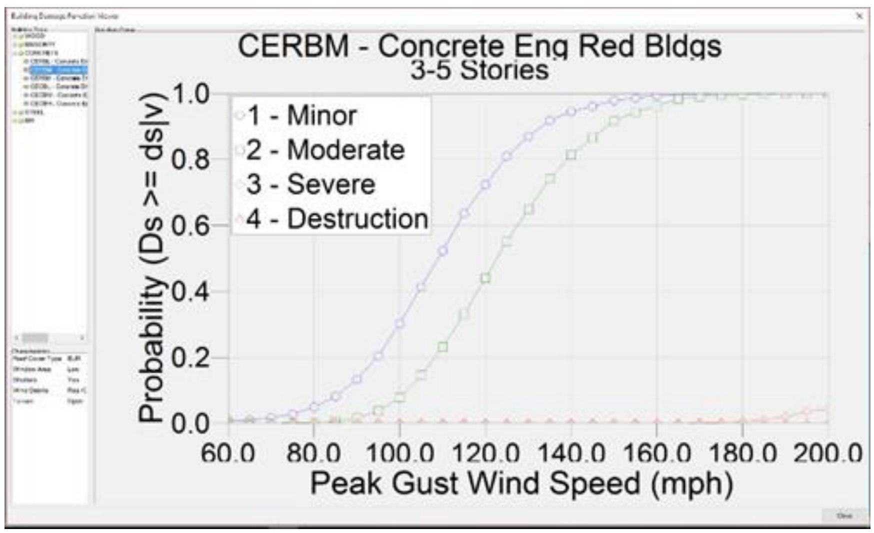

MERBH - Masonry Eng Res Bldgs
6 or More Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

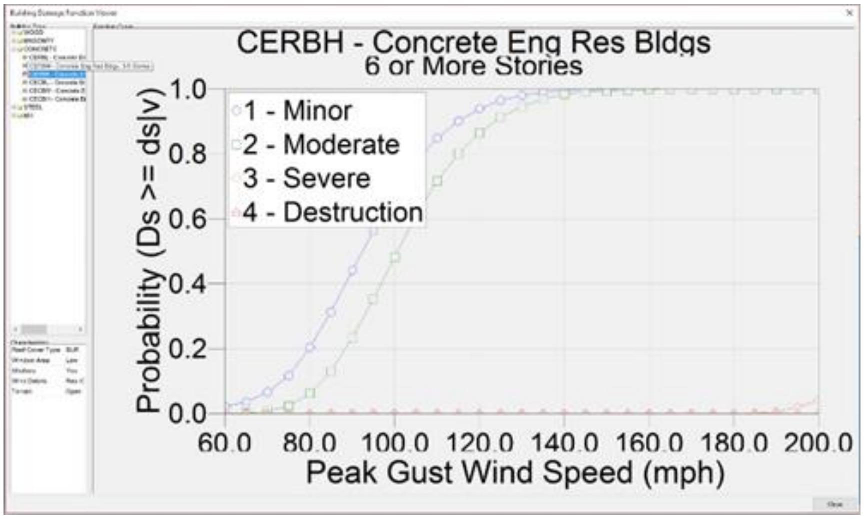

MECBL - Masonry Eng Com Bldgs
1-2 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

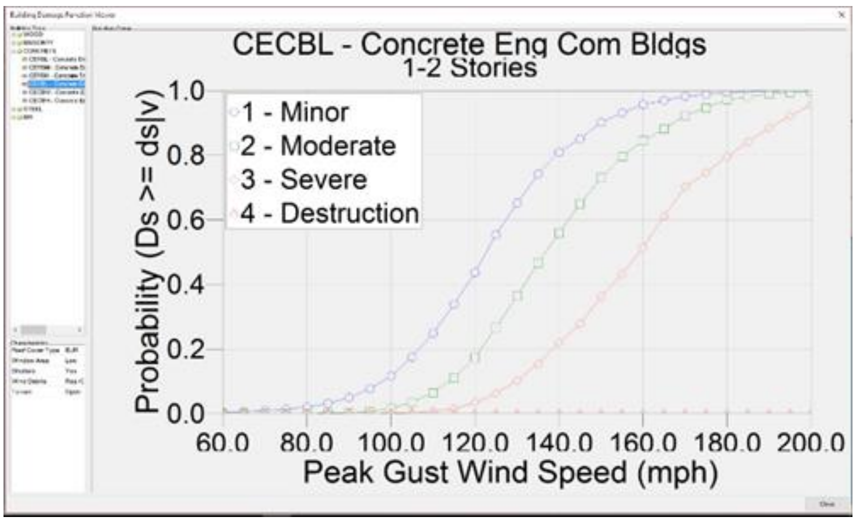

MECBH - Masonry Eng Com Bldgs
6 or More Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

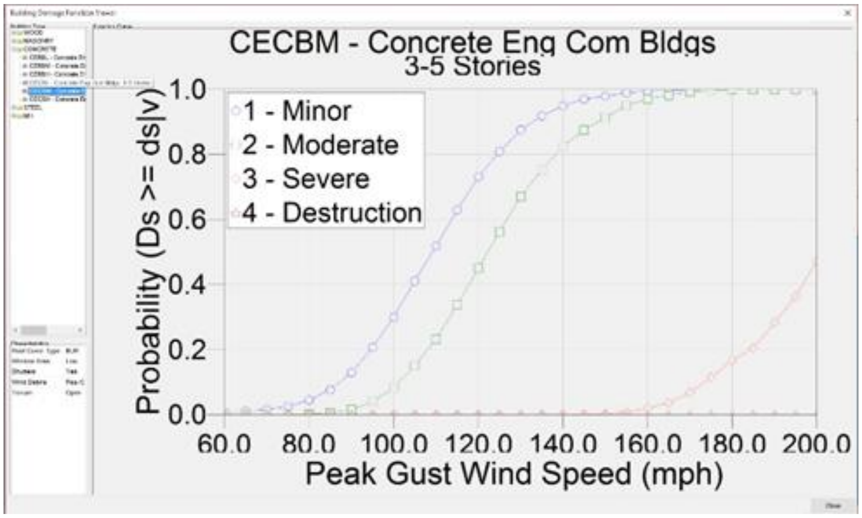
Appendix 3 Concrete Damage Curves

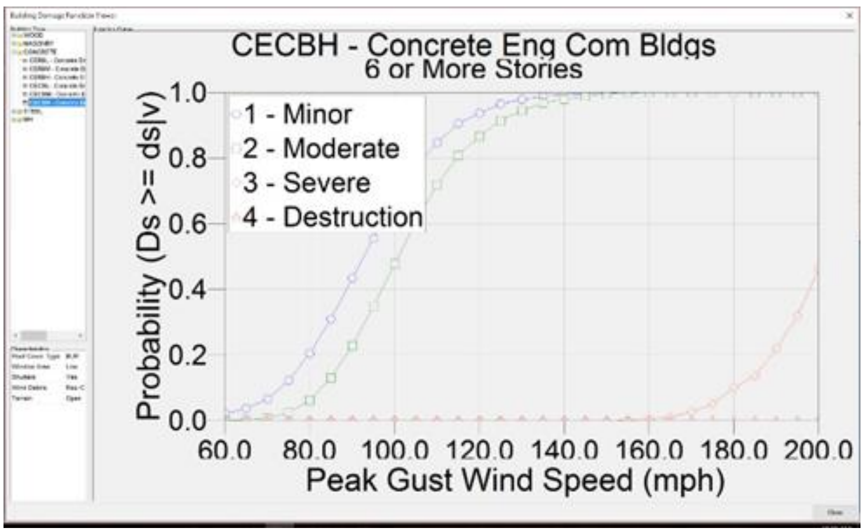




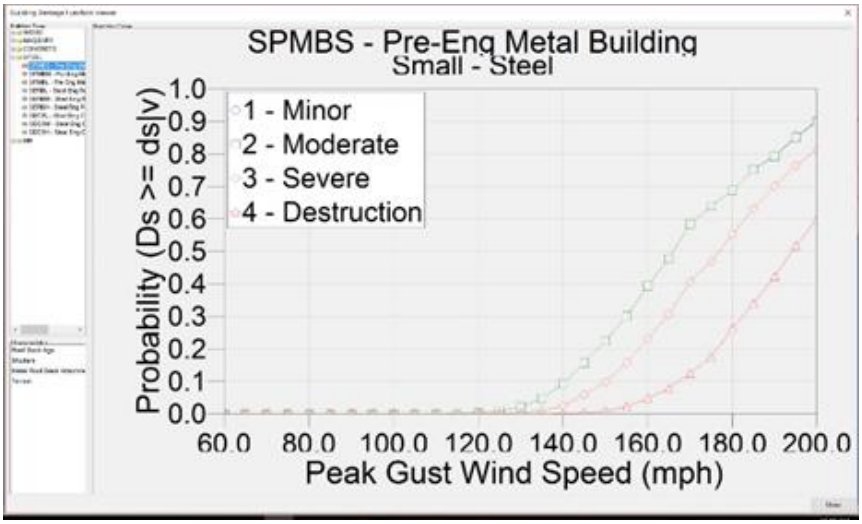

CERBH - Concrete Eng Res Bldgs
6 or More Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

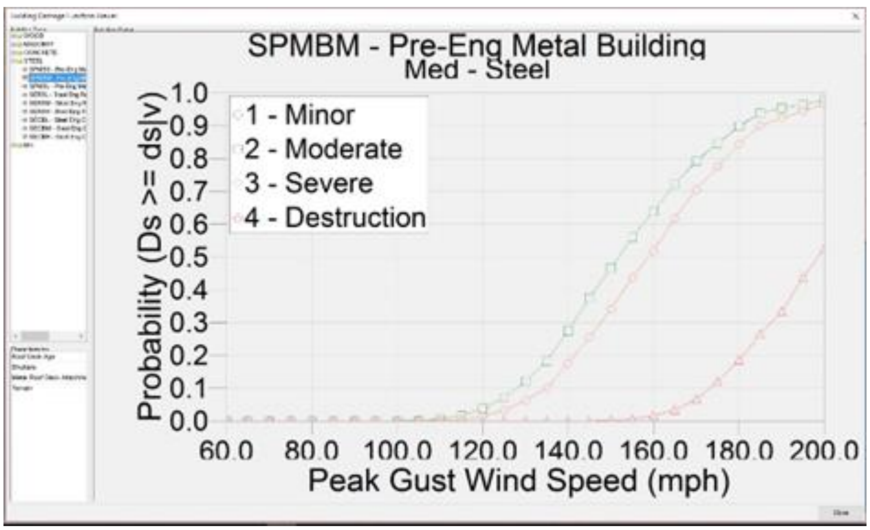

CECBL - Concrete Eng Com Bldgs
1-2 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

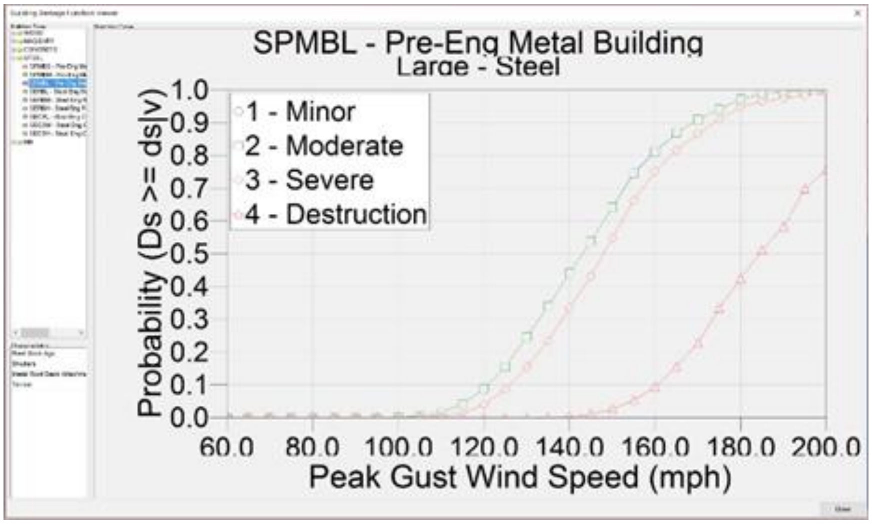

CECBM - Concrete Eng Com Bldgs
3-5 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

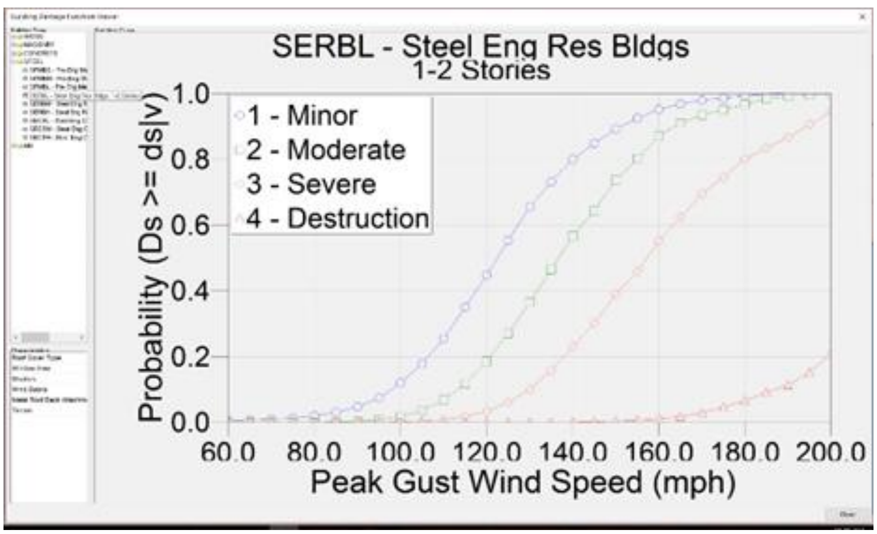

CECBH - Concrete Eng Com Bldgs
6 or More Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

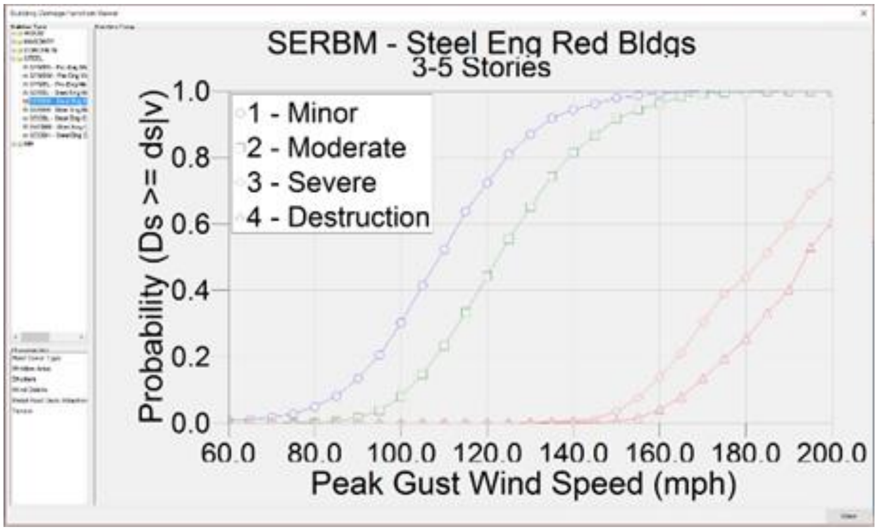
Appendix 4 Steel Damage Curves

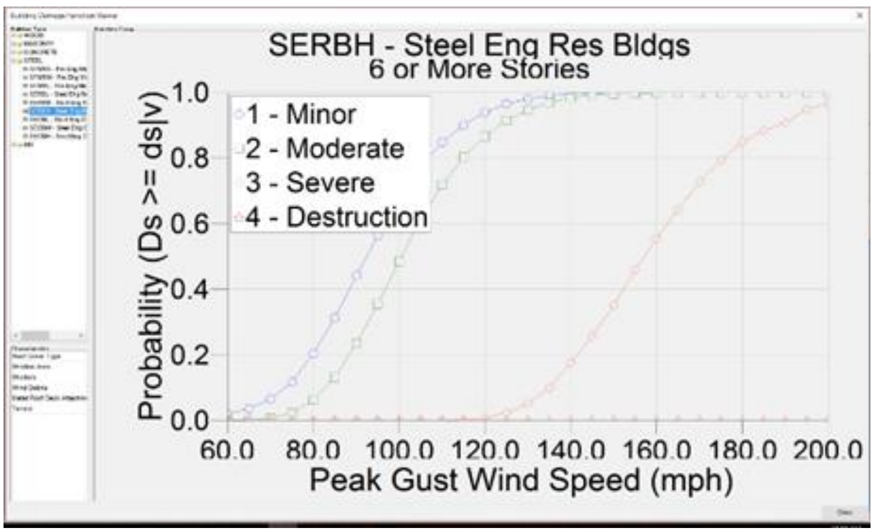


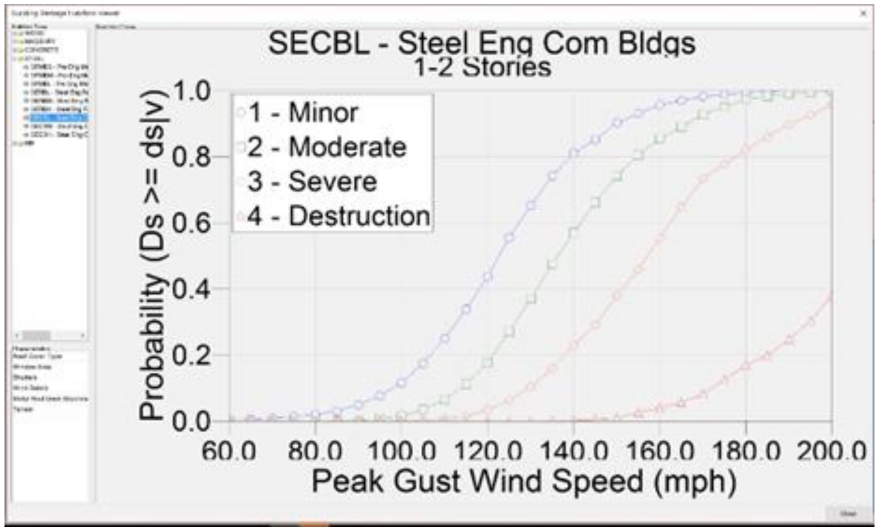


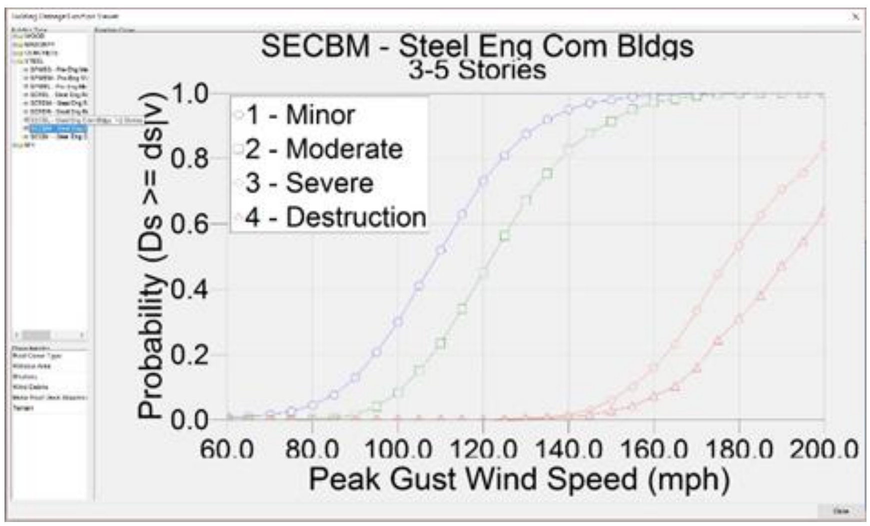

SPMBL - Pre-Eng Metal Building
Large - Steel
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
Peak Gust Wind Speed (mph)

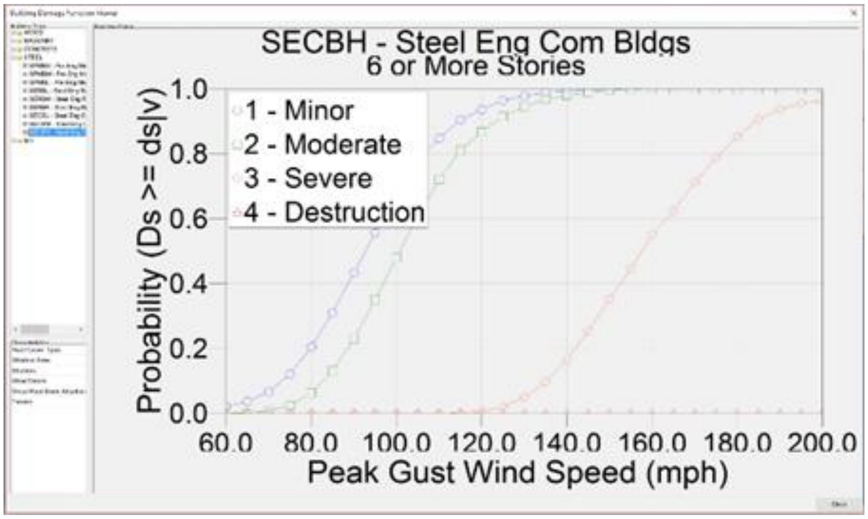

SERBL - Steel Eng Res Bldgs
1-2 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
Peak Gust Wind Speed (mph)


SERBM - Steel Eng Red Bldgs
3-5 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
Peak Gust Wind Speed (mph)

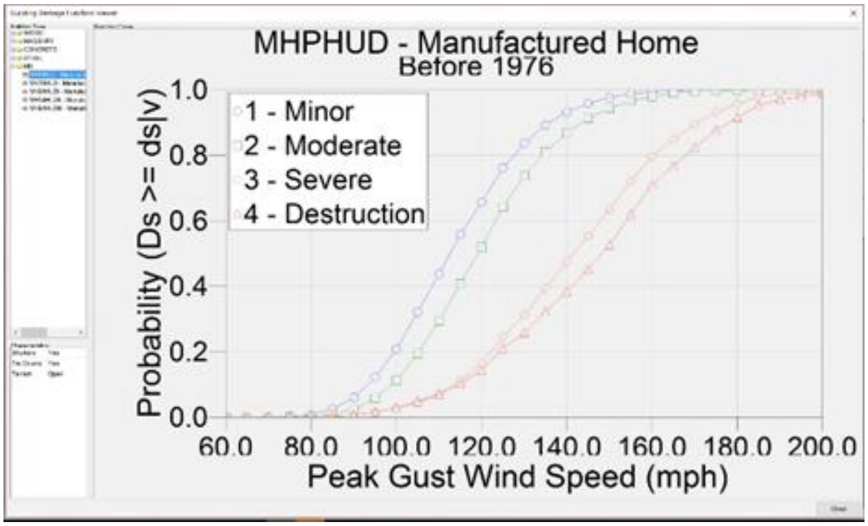

SERBH - Steel Eng Res Bldgs
6 or More Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
Peak Gust Wind Speed (mph)

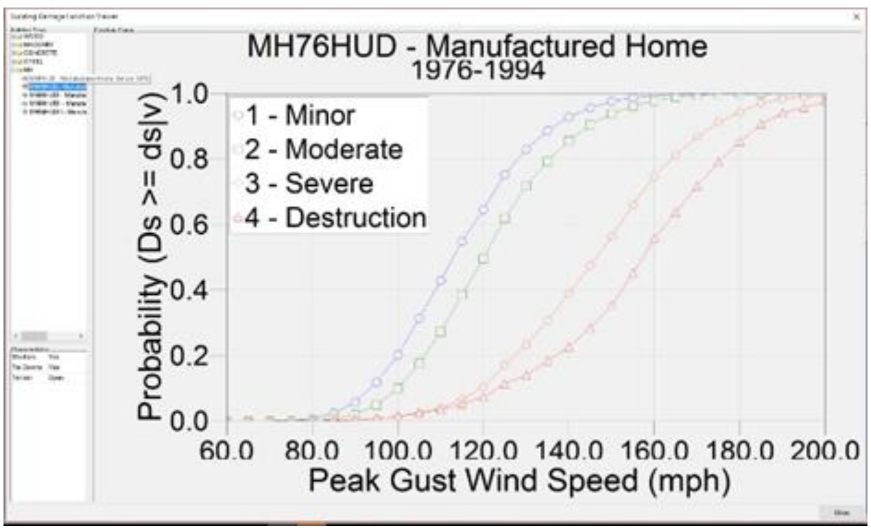

SECBL - Steel Eng Com Bldgs
1-2 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
0.0
0.2
0.4
0.6
0.8
1.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

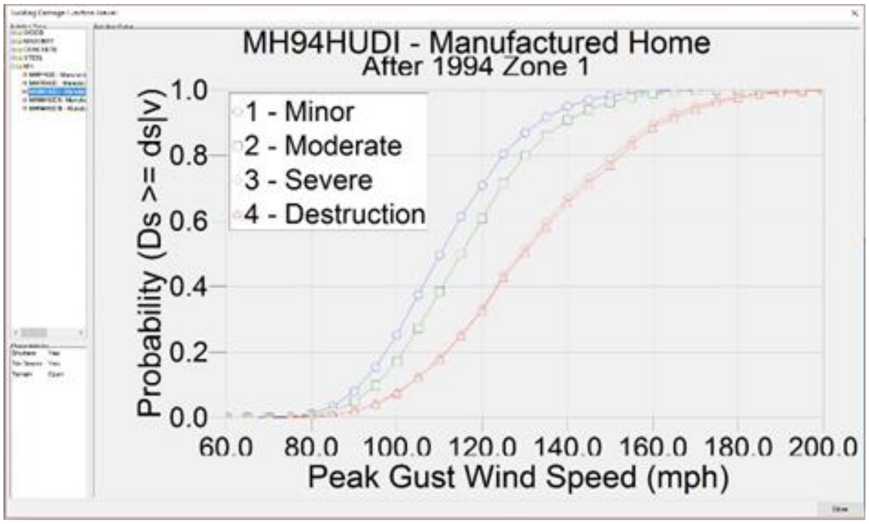

SECBM - Steel Eng Com Bldgs
3-5 Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
0.0
0.2
0.4
0.6
0.8
1.0
60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0
Peak Gust Wind Speed (mph)

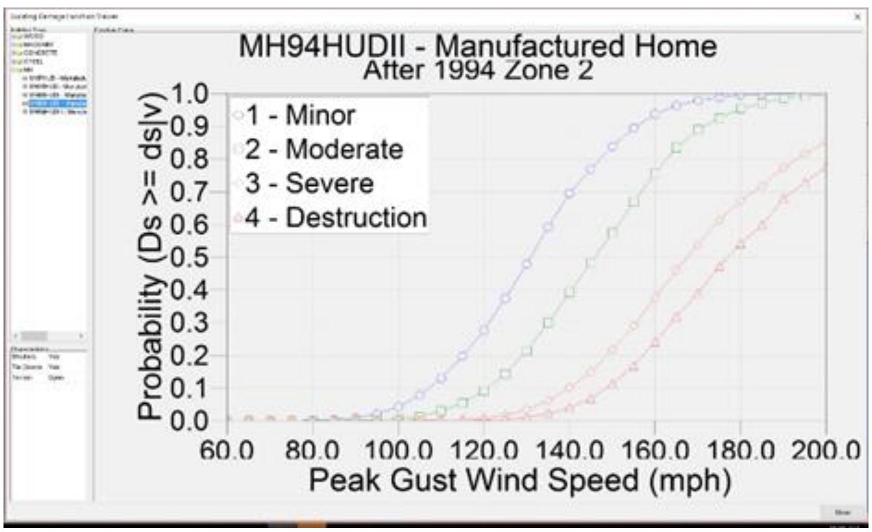

SECBH - Steel Eng Com Bldgs
6 or More Stories
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

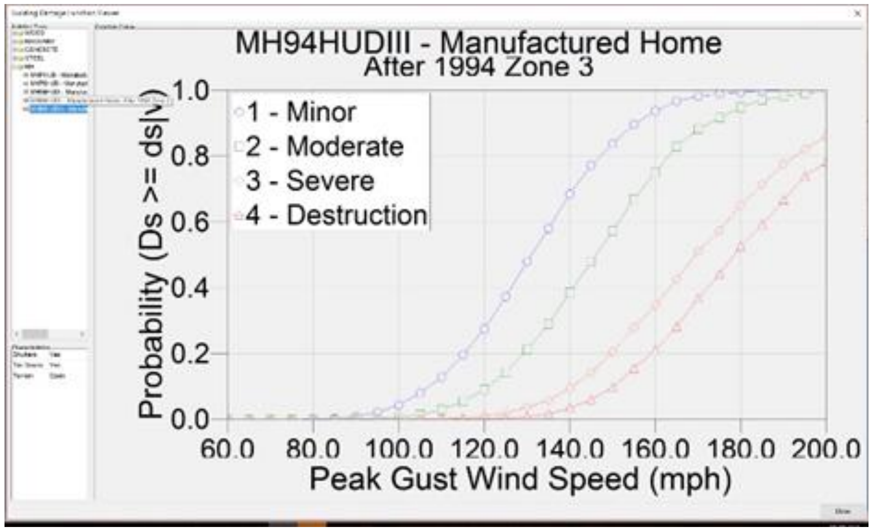
Appendix 5 Manufactured Home Damage Curves



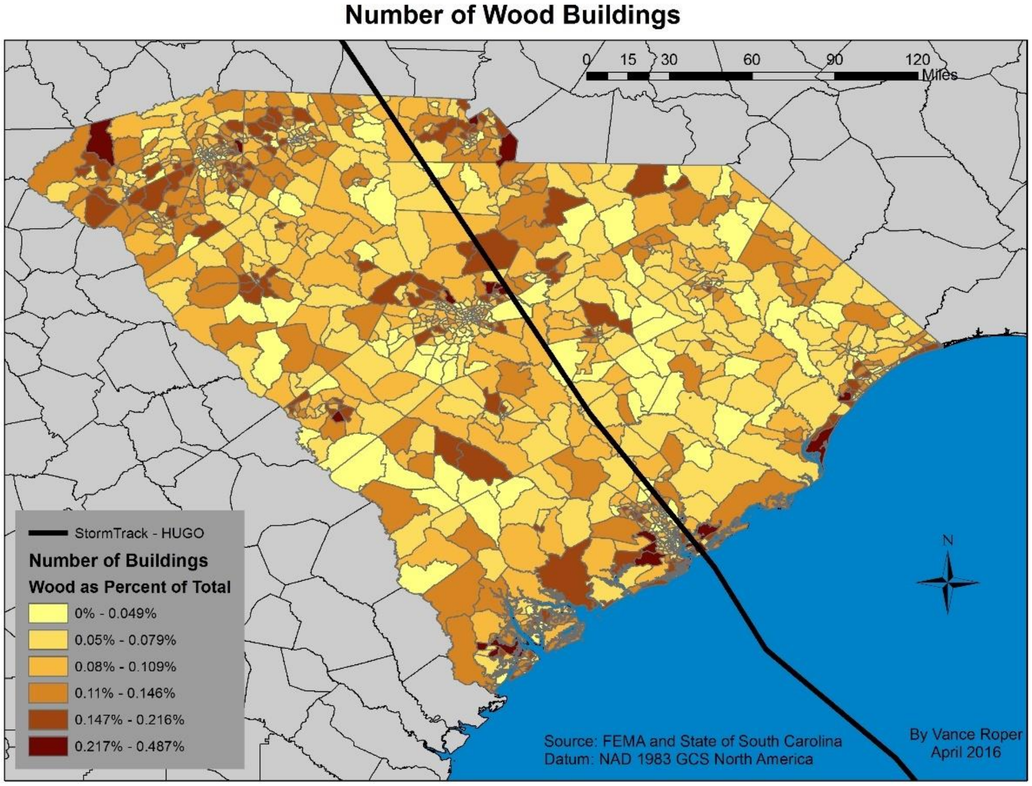



MH94HUDI - Manufactured Home
After 1994 Zone 1
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
0.0
0.2
0.4
0.6
0.8
1.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

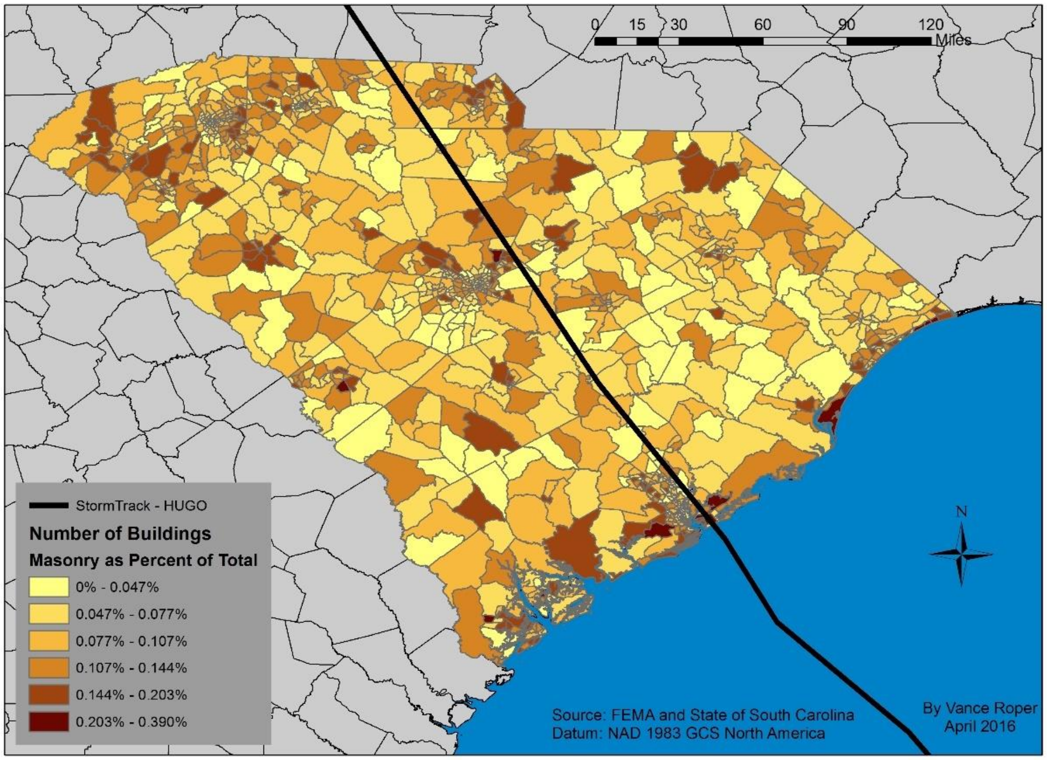

MH94HUDII - Manufactured Home
After 1994 Zone 2
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|v)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)


MH94HUDIII - Manufactured Home
After 1994 Zone 3
1 - Minor
2 - Moderate
3 - Severe
4 - Destruction
Probability (Ds >= ds|V)
1.0
0.8
0.6
0.4
0.2
0.0
60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
Peak Gust Wind Speed (mph)

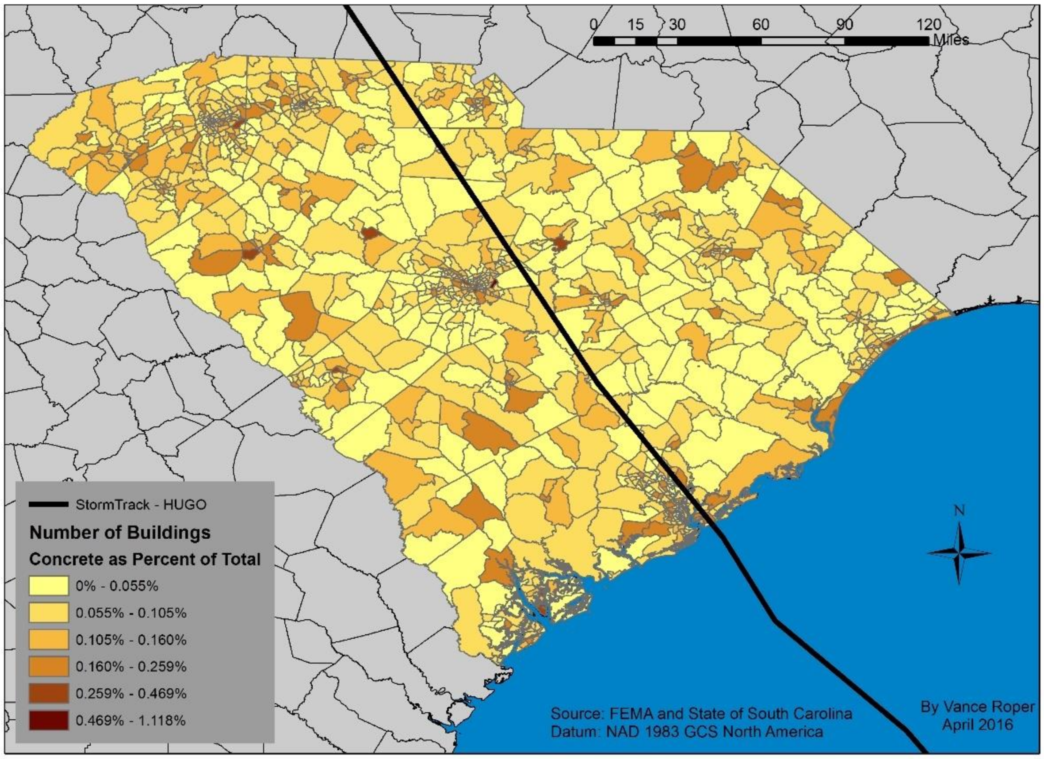
Appendix 6 Building Count



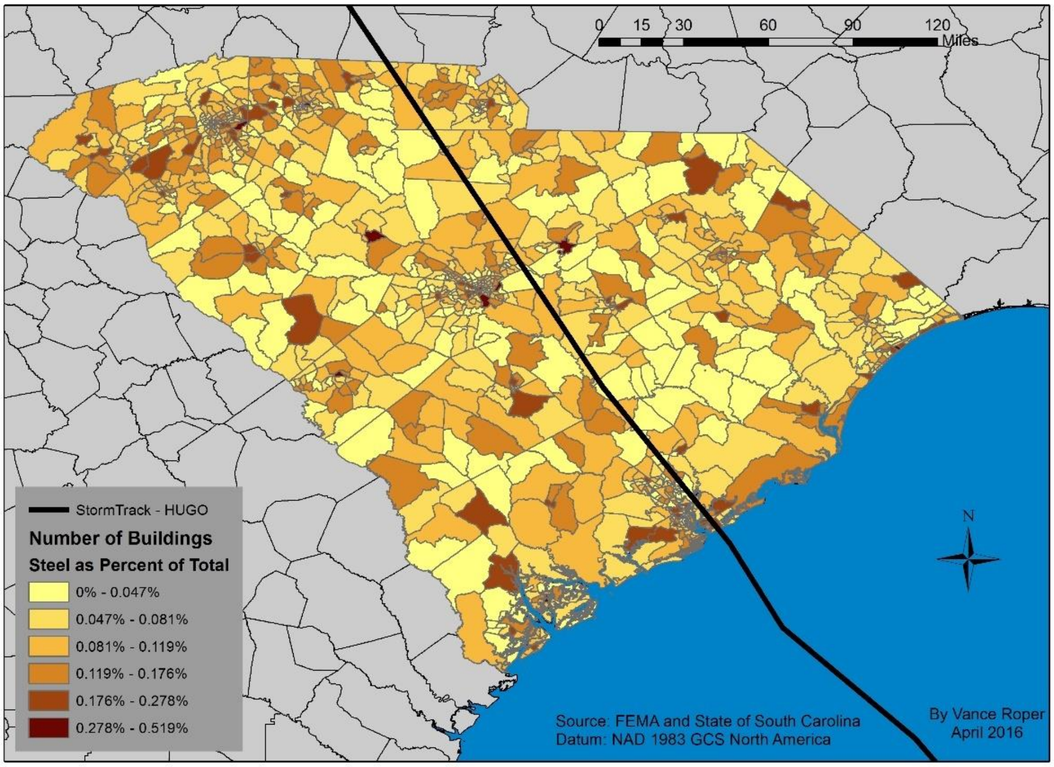
Number of Masonry Buildings



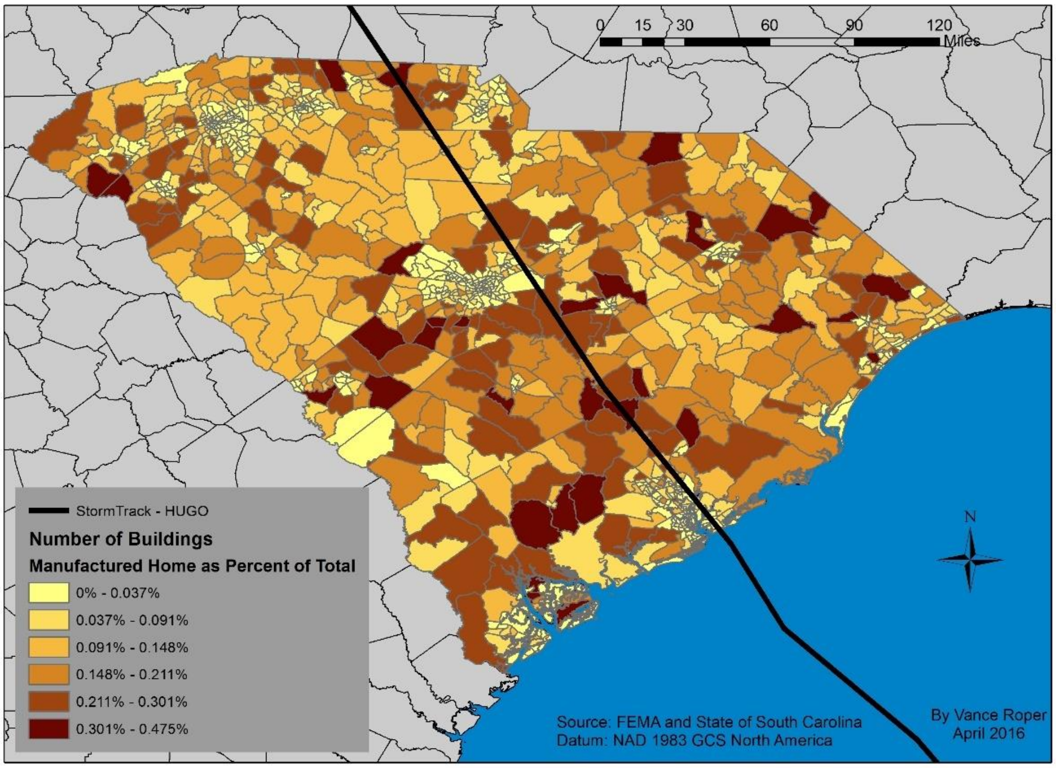
Number of Concrete Buildings



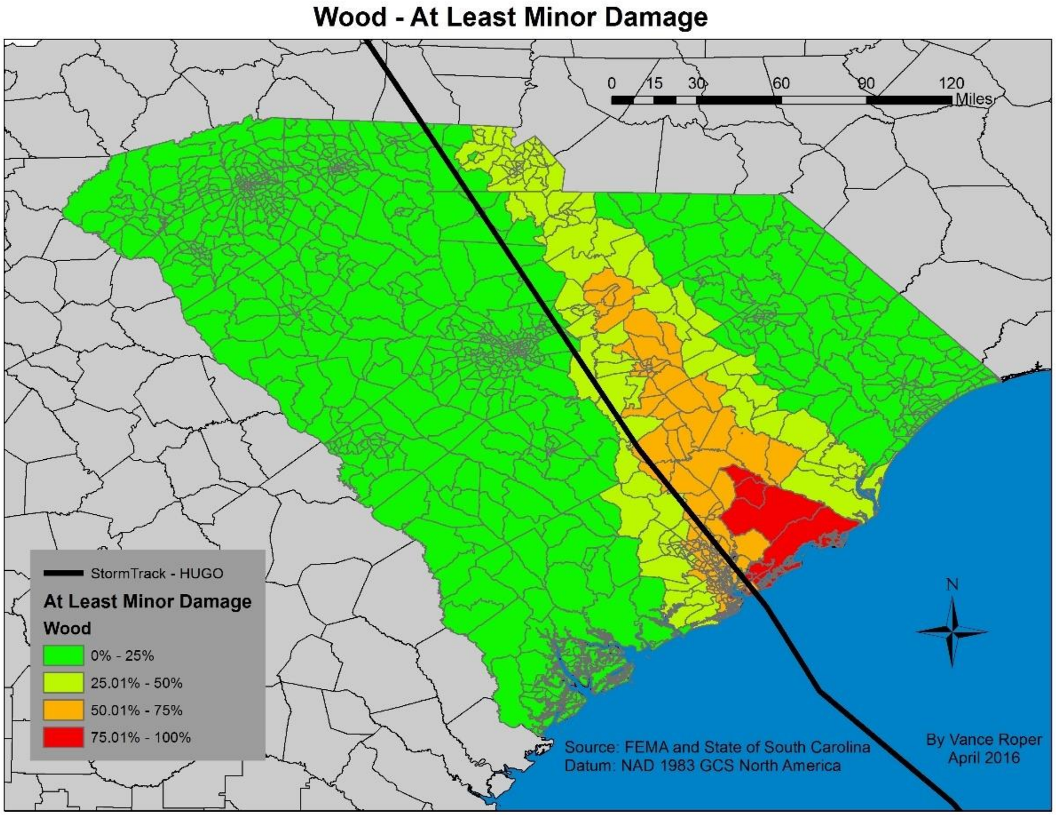
Number of Steel Buildings



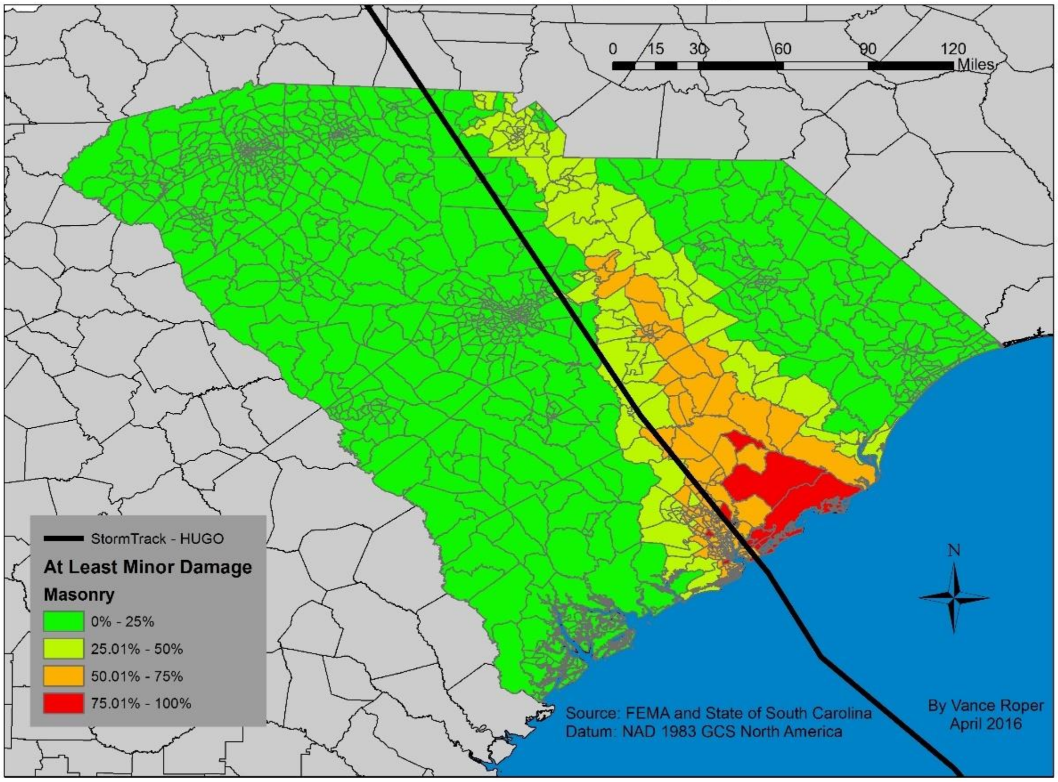
Number of Manufactured Buildings



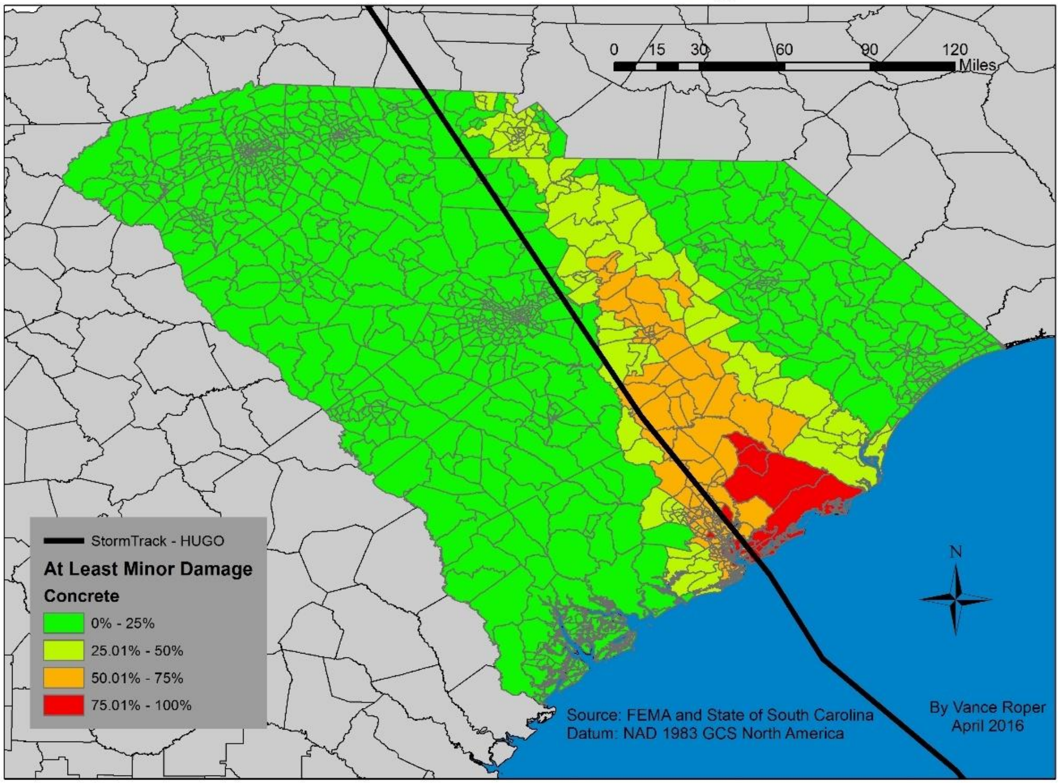
Appendix 7 Damage Maps



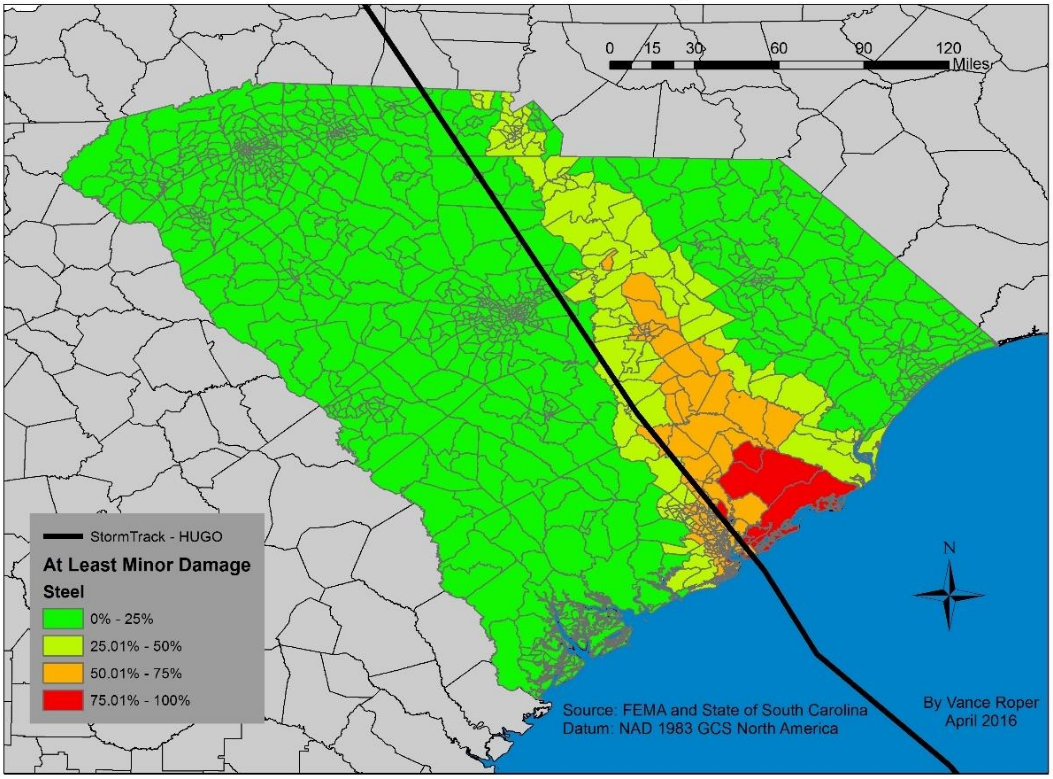
Masonry - At Least Minor Damage

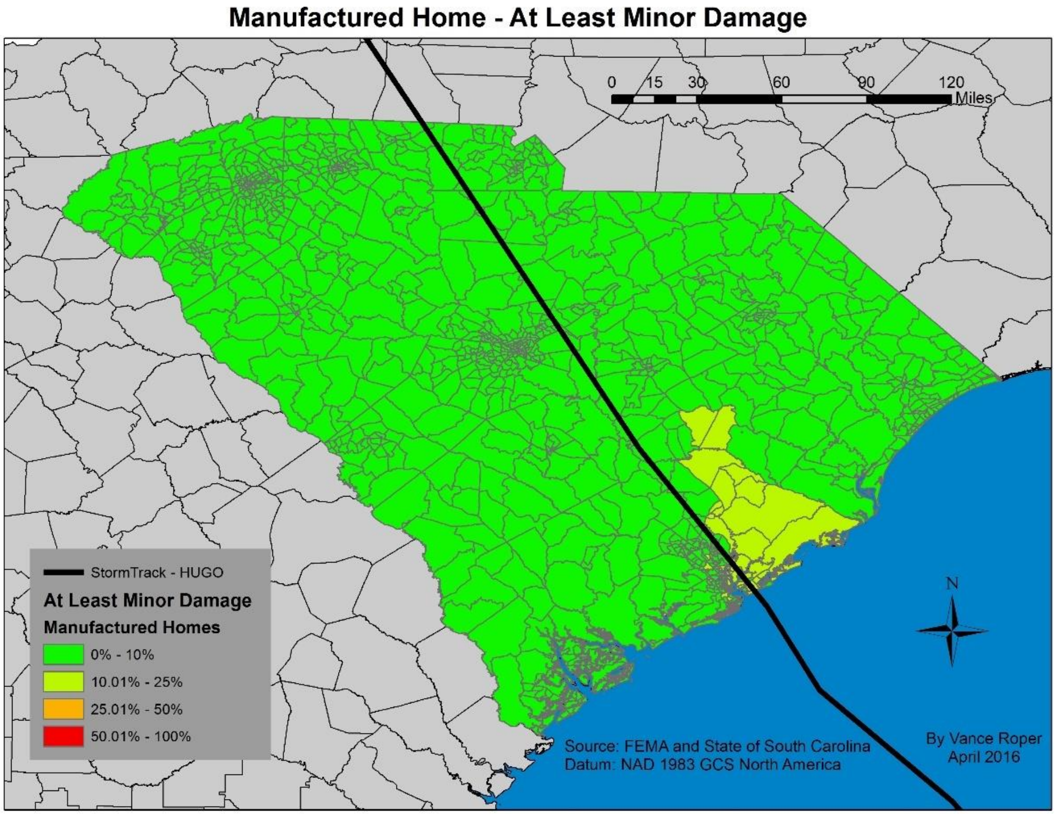


Concrete - At Least Minor Damage



Steel - At Least Minor Damage




Manufactured Home - At Least Minor Damage
0
15
30
60
90
120
Miles
StormTrack - HUGO
At Least Minor Damage
Manufactured Homes
0% - 10%
10.01% - 25%
25.01% - 50%
50.01% - 100%
N
Source: FEMA and State of South Carolina
Datum: NAD 1983 GCS North America
By Vance Roper
April 2016

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