TROPICAL CYCLONE MODELING

UNIT 3

RMS® CCRA® Training Program

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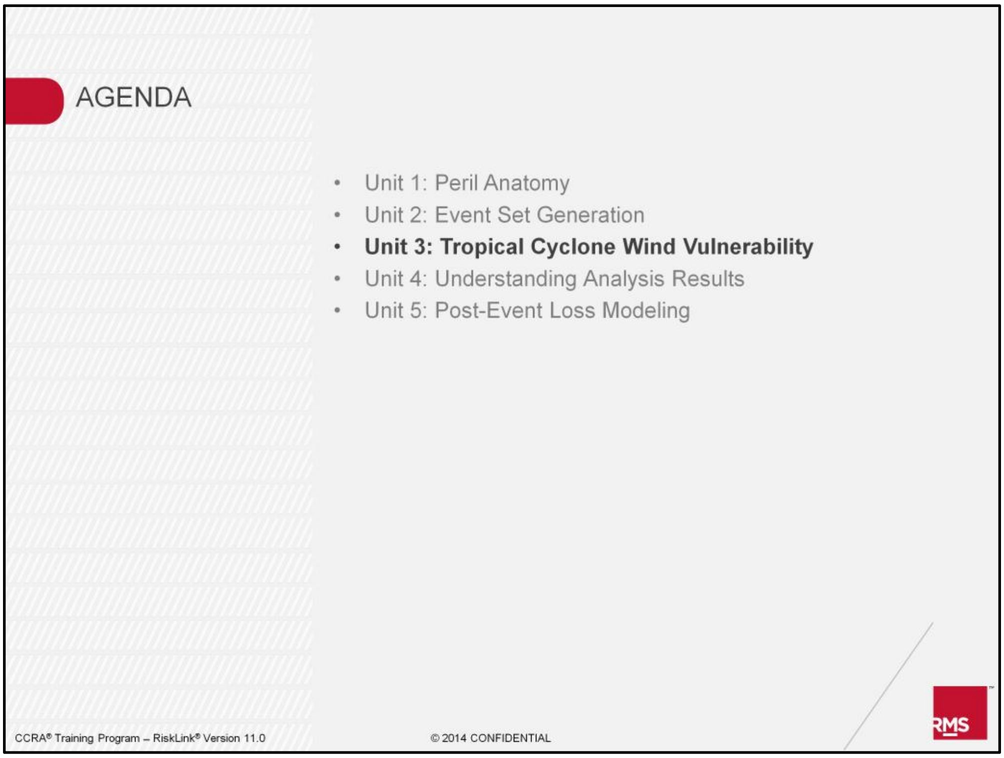
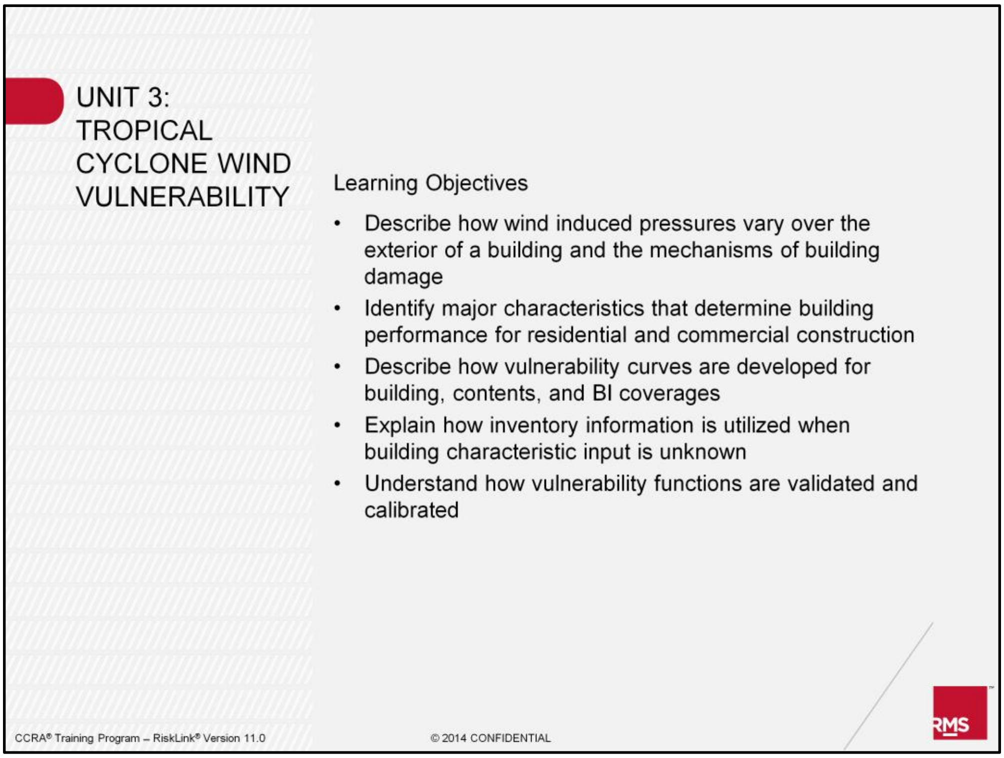


This is the agenda for the Tropical Cyclone Modeling course.The third of five presentation units in this course covers wind vulnerability modeling. This unit includes the following topics:

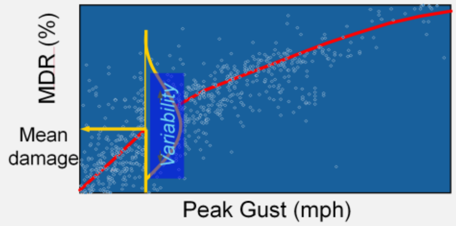
- Wind effects on buildings
- Regional vulnerability considerations and building codes
- Residential building vulnerability
- Commercial building vulnerability
- Other primary vulnerability characteristics (occupancy and year built)
- Secondary construction modifiers
- Development of wind vulnerability functions (structure, contents, and business interruption)
- Building construction inventory
- Vulnerability model calibration and validation
- Loss amplification



At the end of this unit you should have a good understanding of each of the six learning objectives listed on this slide.

VULNERABILITY CLASSIFICATION – FUNDAMENTAL REVIEW

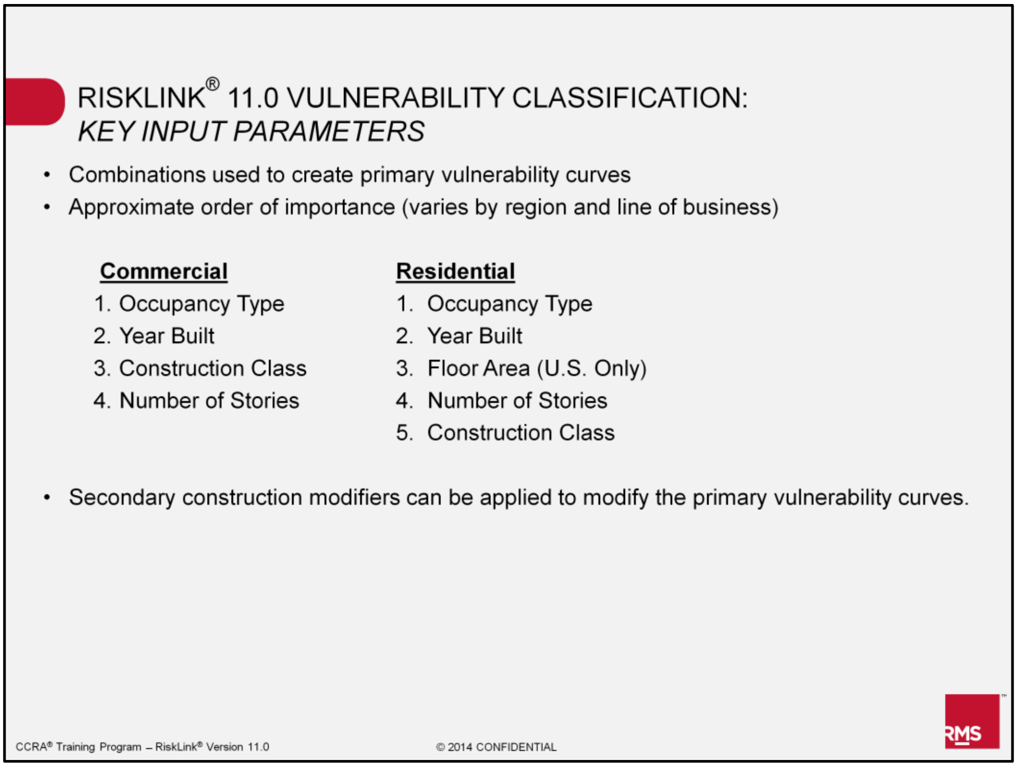
- Vulnerability model provides relationship between peak wind gust and damage (MDR) and associated uncertainty.
- Damage represented as percent of:
  - Building replacement cost
  - Contents value
  - Time element coverage



- Vulnerability functions are region-specific and vary by construction class, occupancy class, year built, height, and floor area (residential U.S. Only).
- Vulnerability functions are calibrated with actual damage and loss data from past tropical cyclones.

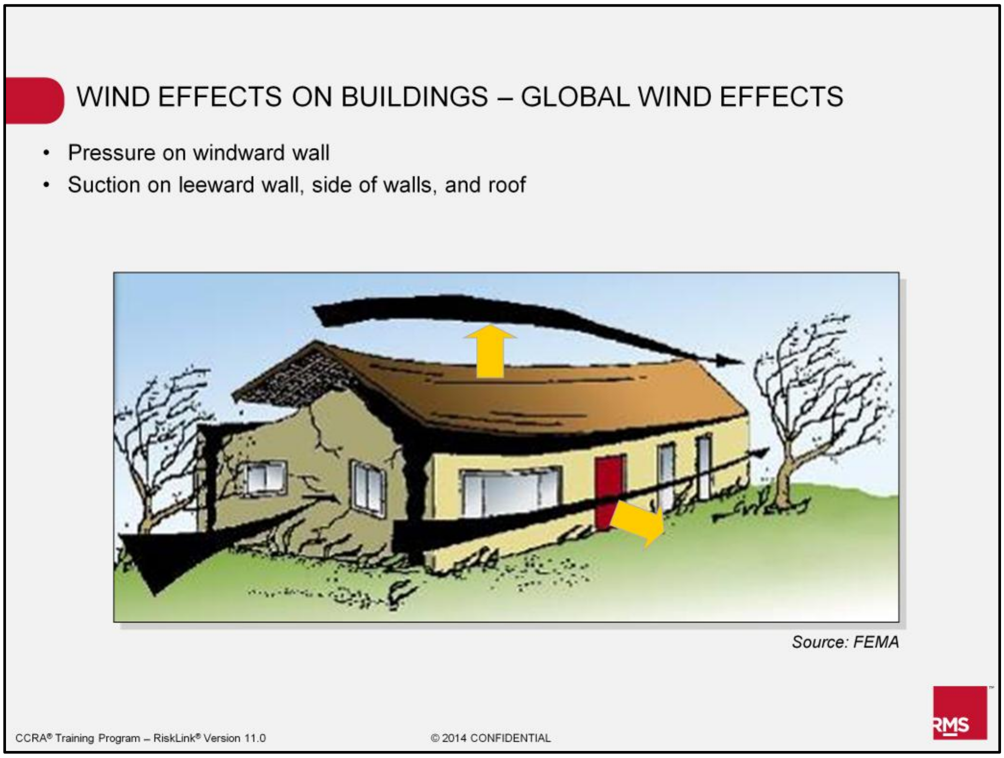
This course starts with a fundamental review of vulnerability and vulnerability functions.

A vulnerability function is simply the relationship between wind speed and damage ratio where the damage ratio is the repair cost divided by the value of the coverage (building, contents, or business interruption). Separate vulnerability functions are developed for buildings, contents, and time-element coverages. The vulnerability functions, as you will see later, are region specific and vary by construction class, occupancy class, age, height, and floor area (U.S. residential only). The vulnerability functions are developed using a combination of analytical approaches and calibrated with past event loss data.



This slide lists the key input parameters for classifying site wind vulnerability. Based on these classifications (with the exception of the secondary modifiers), primary vulnerability curves are created. These primary curves are further altered if secondary construction modifiers are identified. Note that the input parameters are listed by order of importance in terms of impact on modeled losses. The order of importance varies by line of business as well as by vulnerability region (discussed on a later slide).

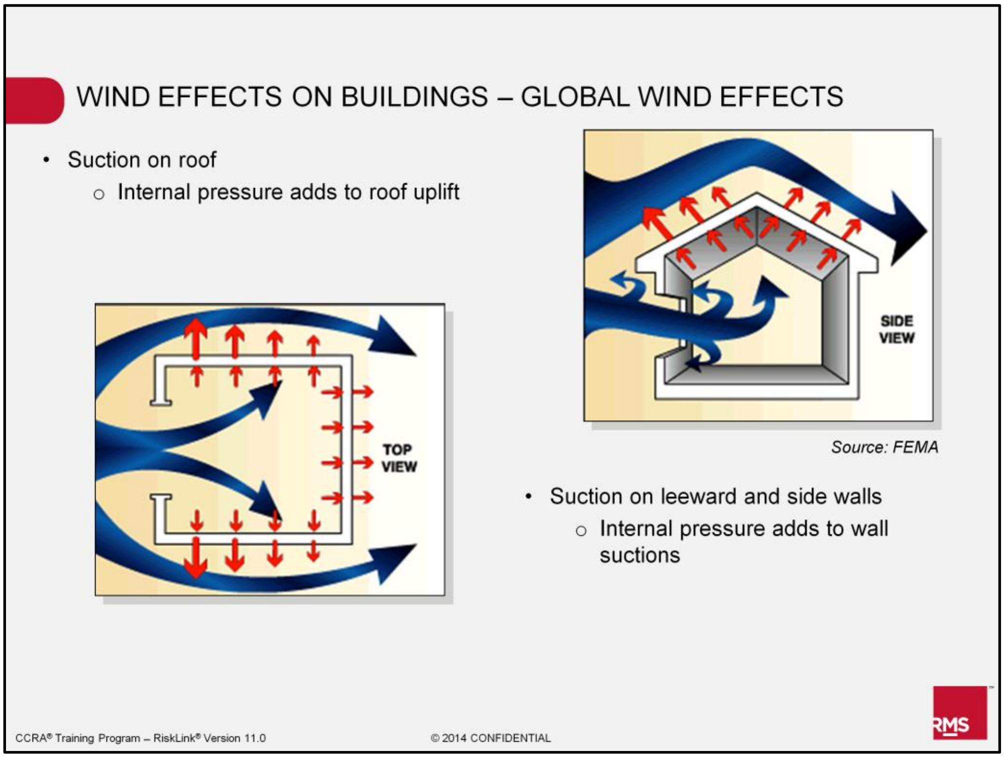
The majority of this presentation will address these parameters (also termed as primary characteristics) and the impact of secondary construction modifiers in more detail.



Prior to discussing the vulnerability parameters, we will first review the impact of wind pressure on a building during a hurricane.

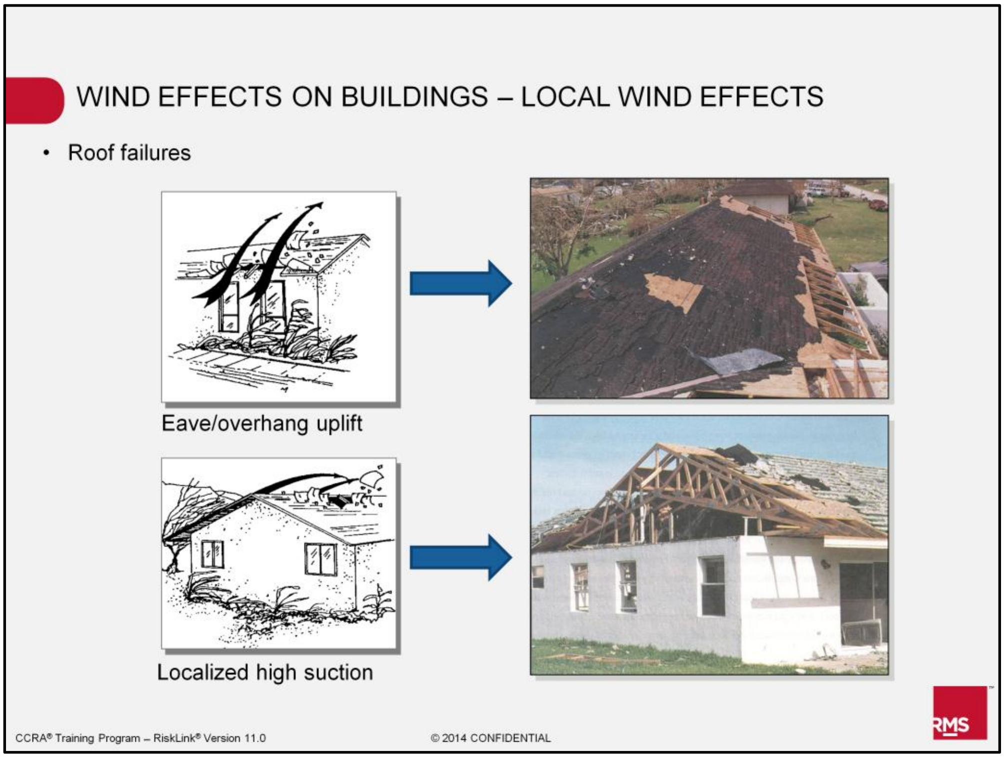
This graphic provides a simple illustration. As the wind hits the front windward wall of the building, it creates an inward pressure. However, as the wind passes around the exterior walls and the roof of the building, outward suction portions are created. The outward forces act to pull elements such as roof shingles or windows away from the building.

These aerodynamic forces are analogous to what happens on an airplane. As the wind passes over the curved top portion of the wing, it has to travel faster than the wind that passes below the wing. The pressure on the air going over the wing is less than the pressure of the slower moving air below the wing, causing an uplift force.

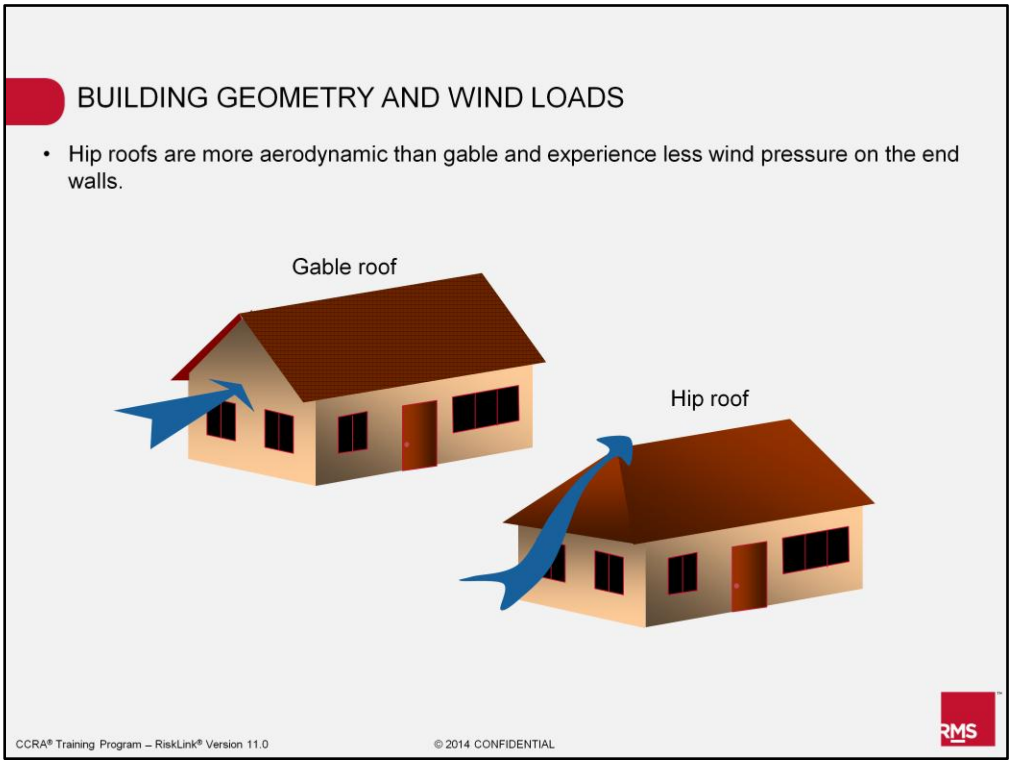


This slide shows illustrations of how internal pressurization can increase the loading on building elements. In the figure on the upper right, suction forces are shown by red arrows above the roof. If there is an opening in the wall, for instance if a window breaks, pressure will increase on the interior of the building resulting in additional upward forces on the roof, illustrated by the red arrows below the roof.

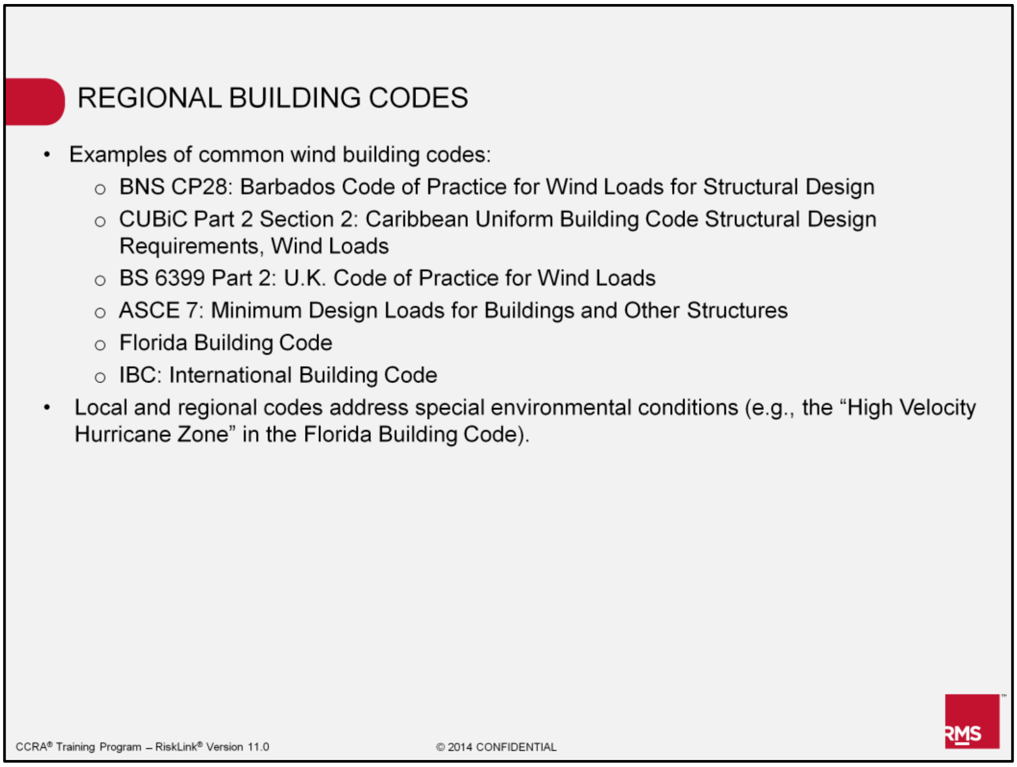
The graphic in the lower left shows a planned view looking down from above and illustrates the additional pressure on the walls caused by internal pressurization.



In addition to the global wind pressures exerted on a building described in the prior slides, localized, larger pressures can also occur, typically at building discontinuities. Examples are at the eaves or ridge of a house, as illustrated in these graphics. Local vortices can create pressures in these regions much greater than the average pressure across an entire building. This is why we often see the greatest damage at the corners and edges of roofs.

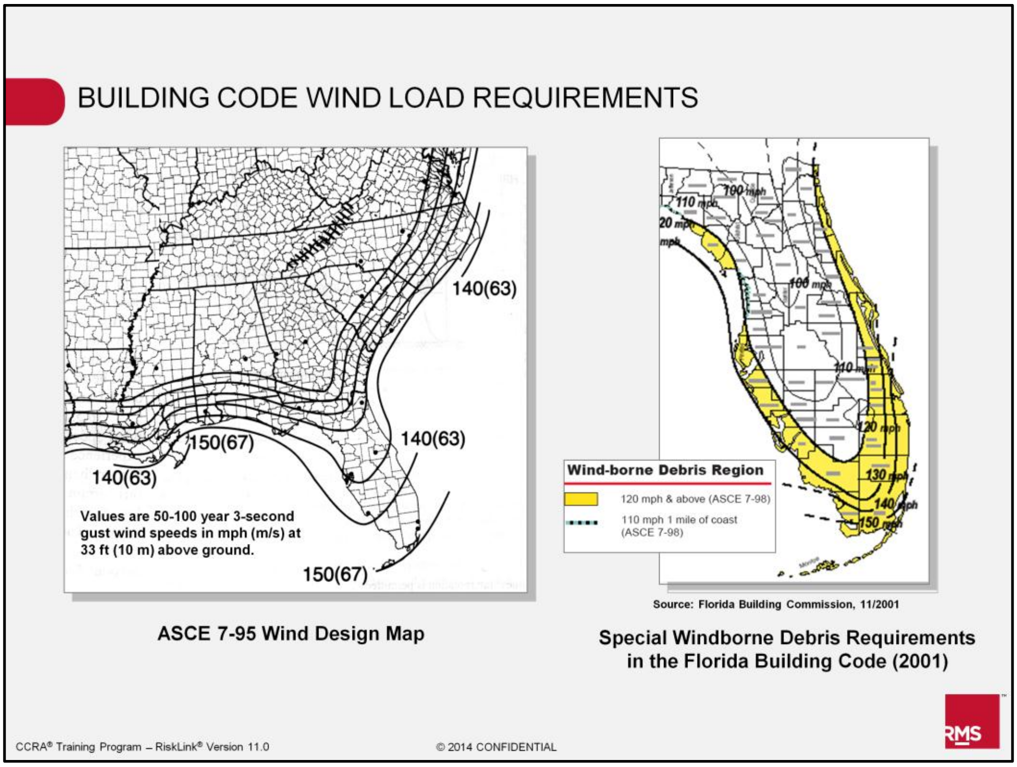


Given that the shape of a building can determine the magnitude of localized wind pressures, the extent of building damage will be impacted by building configuration. For example, a hip roof is much more aerodynamic than a gable-end roof configuration. Therefore, the local pressures on the hip roof will be less than those of the gable roof and everything else being equal, the hip roof would be expected to experience less damage. Of course, other factors, such as the strength of the roof elements and quality of construction, will play a large role and determine the extent of damage in an actual event.



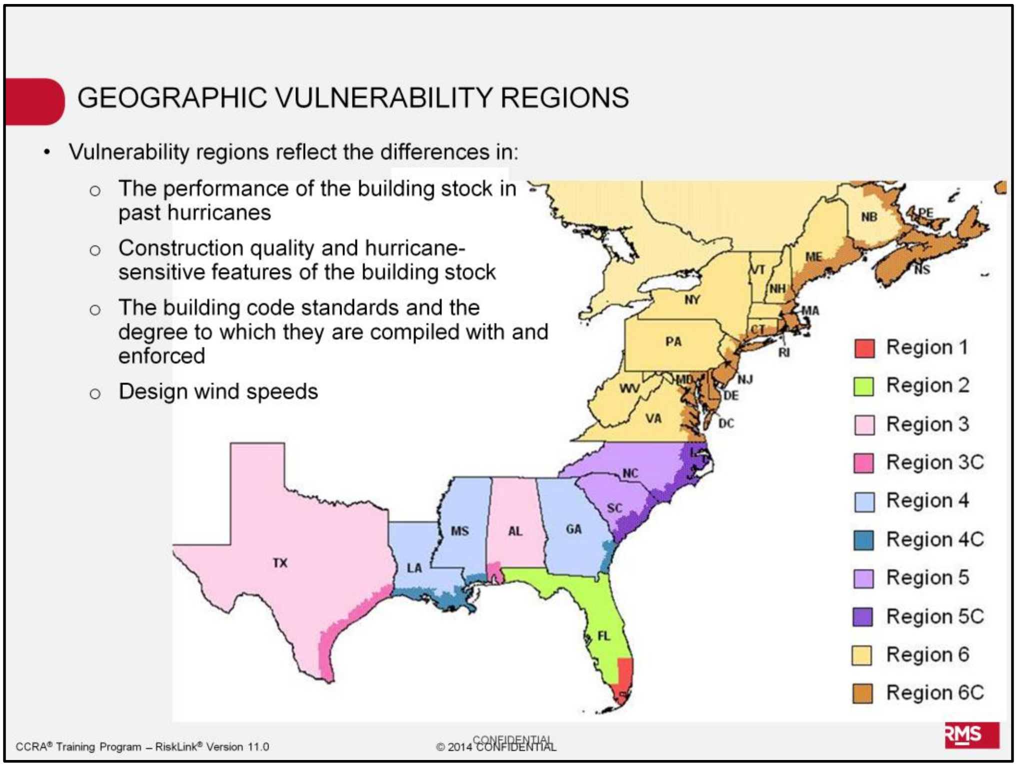
Having discussed some of the factors that determine the magnitude of wind pressures on a building, building code design requirements will now be discussed.

In just about any country or region, a building code will specify the wind pressures for which a new building should be designed. We have listed a number of examples on this slide. In the United States, it is typically at a state level where a determination is made regarding what building code is used. However, local jurisdictions can add additional requirements. The building codes address the design wind speeds as well as the pressures that must be designed for across a building's exterior.



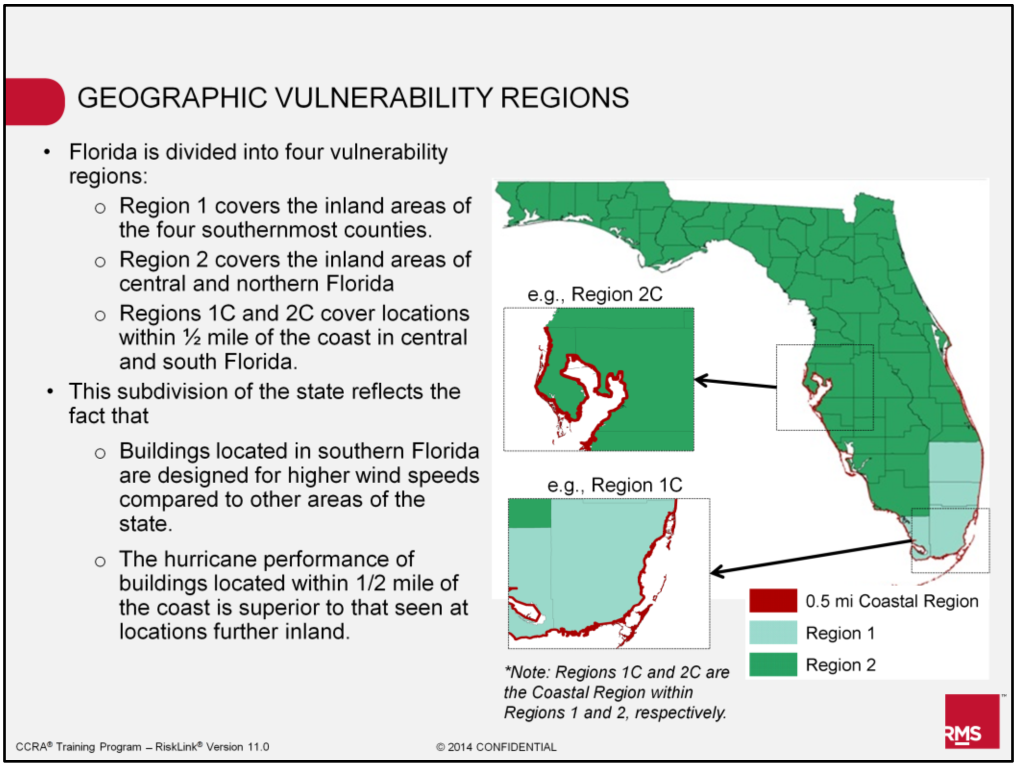
This slide shows a couple of simple examples of a wind speed design map. Given the location, the design wind speed for a new building can be determined by interpolating between wind speed contours. You can see that design wind speeds are greatest along the coast and decrease inland, as would be expected. The return periods of these design wind speeds vary depending on the code but are typically in the 50- to 100-year return period range.

In addition to specifying design wind speeds, codes can also designate special design areas, as illustrated in the graphic on the right, showing regions where wind-borne debris must be considered in Florida.



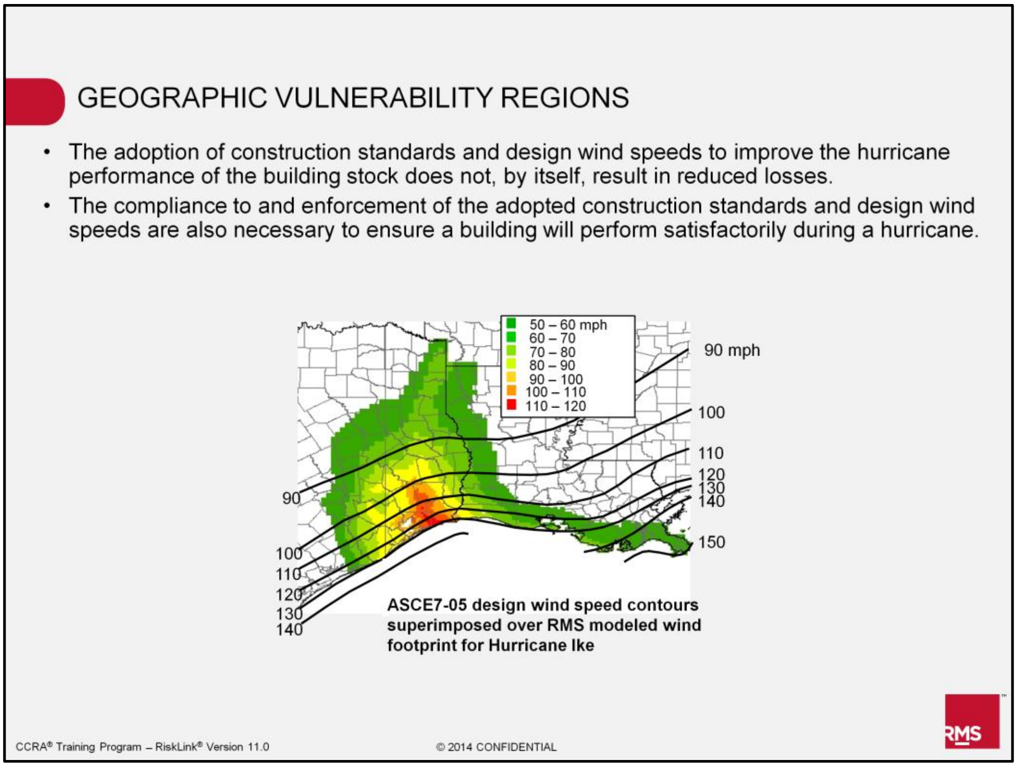
The U.S. hurricane wind vulnerability model is region-specific. Extensive studies have been completed to define the vulnerability regions in the U.S. hurricane model. The vulnerability regions are identified in a way such that they reflect the (mostly man-made) differences in (1) the building performance during previous hurricane events, (2) the construction quality and hurricane-sensitive features of the insured building stock, (3) the quality of building codes and the degree to which they are enforced, and (4) code-stipulated design wind speeds.

Approximately 600 vulnerability curves, corresponding to different combinations of primary building characteristics listed on slide 5, are implemented in each vulnerability region.

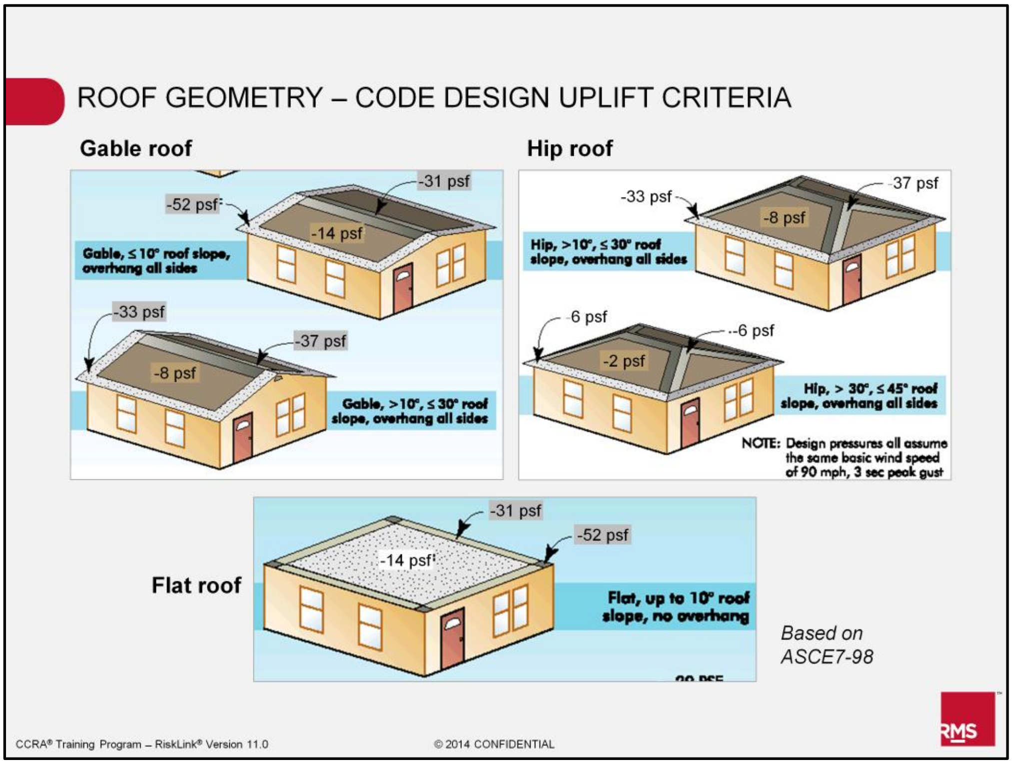


Florida is divided into four vulnerability regions. Region 1 covers the inland areas of the four southernmost counties, Region 2 covers the inland areas of central and northern Florida and Regions 1C and 2C cover locations within 0.5 miles of the coast in central and south Florida. This subdivision of the state reflects the fact that (1) buildings located in southern Florida are designed for higher wind speeds compared to other areas of the state and (2), based largely on trends seen in claims data, the hurricane performance of buildings located within 1/2 mile of the coast is superior to that observed at locations further inland.

The observed superior performance of the building stock in the coastal vulnerability regions is likely due to (1) greater attention paid to the design and construction of buildings to wind loads, (2) greater enforcement of compliance to the relevant building code provisions in these areas, and (3) generally greater awareness of the risk, causing property owners to exercise greater care in maintaining and protecting their properties.



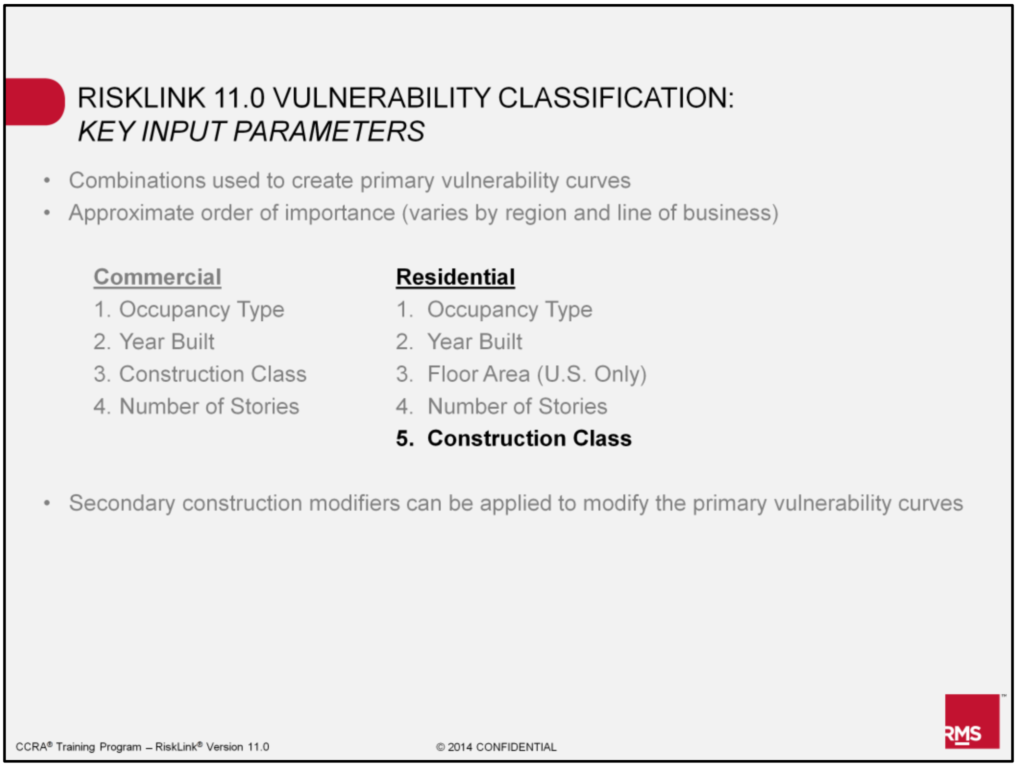
The adoption of construction standards and design wind speeds to improve the hurricane performance of the building stock does not, by itself, result in reduced losses. The compliance to and enforcement of the adopted construction standards and design wind speeds are also necessary to ensure a building will perform satisfactorily during a hurricane. For example, reports by the Federal Emergency Management Agency (FEMA) and the Roofing Industry Committee on Weather Issues (RICOWI) following Hurricane Ike provide strong evidence that the building envelopes and roof systems in Texas failed at wind speeds lower than engineering principles and building codes would suggest, implying construction quality issues in Texas related to the lack of building code compliance and enforcement known to exist in the state.



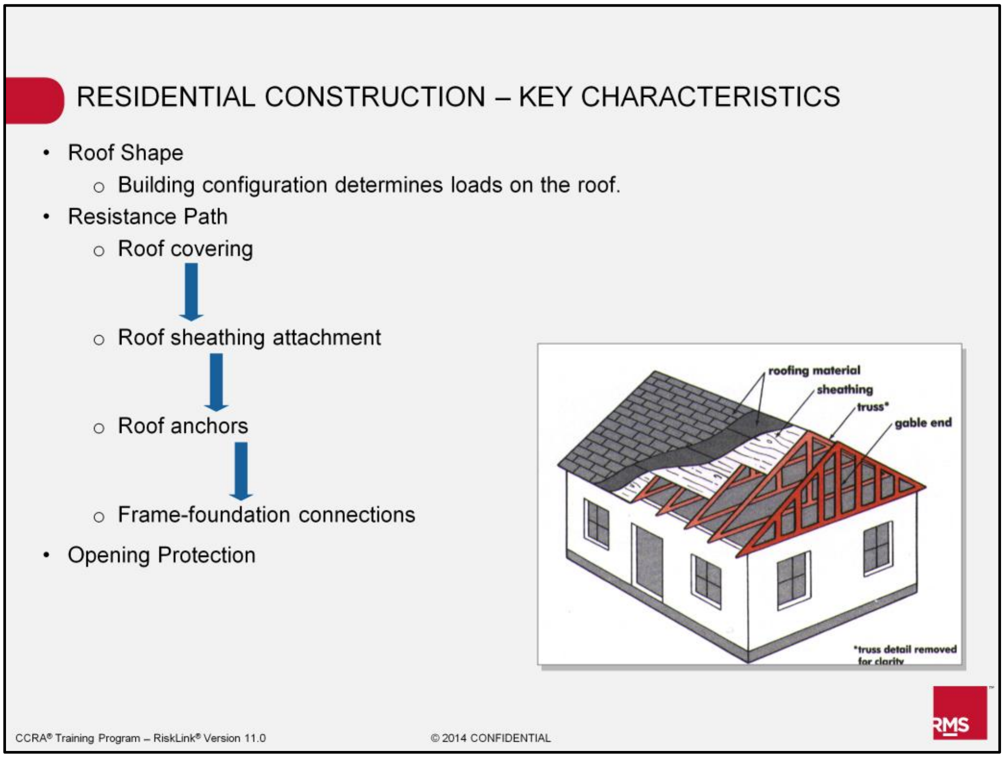
In addition to specifying the design wind speeds, the codes will also specify the design pressures across the envelope of a building. The pressures across a roof will vary depending on the roof shape, as was already mentioned.

In this slide, a negative pressure value, for example, eight pounds per square foot, refers to an upward suction pressure of eight pounds per square foot on that portion of the roof. When looking at the gable-roof pressures in the upper left graphic, it can be seen that the suction forces are greater with a low-pitch roof, in this example 14 pounds per square foot versus eight pounds per square foot for the steeper roof.

It can also be seen that pressures are much greater along the edges and the ridge of a roof. On the hip-roof graphic, it can be seen that the aerodynamic configuration of the roof results in much lower pressures as compared to the gable roof. The flat-roof configuration, shown on the bottom of the slide, shows uplift pressures similar to a low-pitch gable roof.



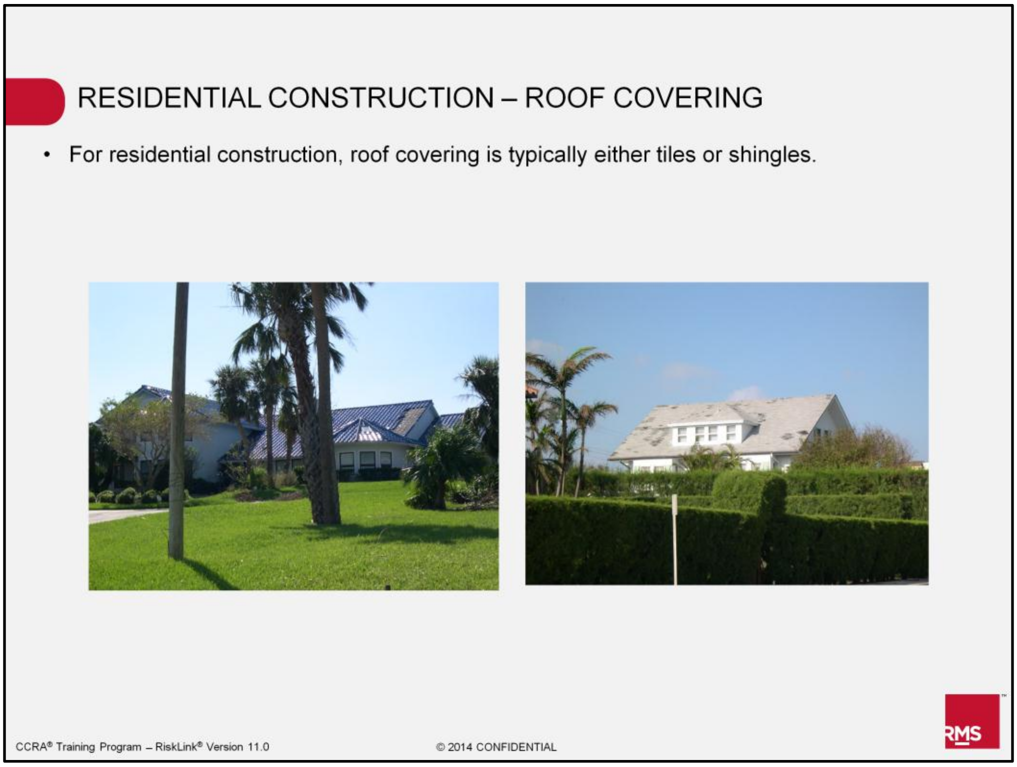
The next set of slides cover the topic of residential construction class – one of the primary construction characteristics listed above.



We can use these types of tools analytically to estimate what the distribution of pressures will be during the course of a hurricane and aid us in our determination of building damage.

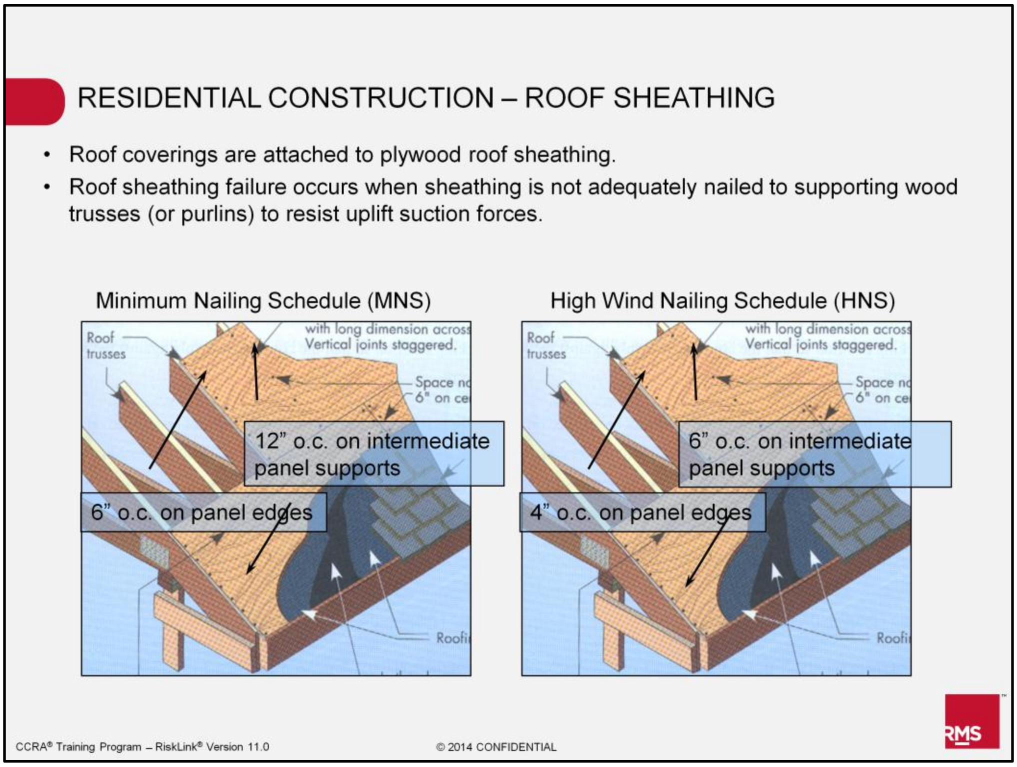
Up to this point, we have discussed how design wind speeds are specified in building codes, how tropical cyclones create pressure lows on buildings, and how those lows vary across the envelope of a building. In this next section of the presentation, we will discuss the key building characteristics that determine how buildings perform when subjected to wind pressures.

Let's first talk about residential construction. A basic single-family dwelling consists of some type of roof covering attached to plywood roof sheathing, which is attached to roof trusses or purlins. The roof trusses then need to be attached to the walls, and finally the walls must be attached to the foundation. All these elements must be connected to resist not only the downward gravity forces of their own weight, which is nearly constant over the life of a building, but also the upward suction forces that act in the opposite direction during a tropical cyclone. All these elements must be sufficiently interconnected in order to resist tropical cyclone winds.



For residential construction, the roofing material is typically tiles or shingles. The manner in which these materials are attached to the roof sheathing will determine how well they resist forces. In older codes, it was common to specify the required size and spacing of nails for attaching shingles to a roof. It is now common for shingles to be rated for a specific wind speed in order to be approved for use in high-risk areas, such as Florida. To obtain a rating, manufacturers must have their products tested in a lab.

Note in the left-hand picture that the missing tiles are located along the edge of the roof, where, as we showed previously, the pressures are highest. Both of these pictures are from Hurricane Jeanne, which hit Florida in 2004.



Continuing down the load path from the roof covering to the foundation, the next element to consider is the roof sheathing upon which the roof covering is attached. Roof sheathing typically comes in plywood or oriented strand board (OSB) panels measuring four feet by eight feet. The panels are nailed to roof framing around the perimeter of the panels as well as the interior of the panel. Nailing around the perimeter of the panel is at a closer spacing to avoid uplift of the panel off of the roof trusses.

Shown in this graphic are two typical nailing schedules. On the left, nails are spaced at six inches apart around the perimeter of the panel and 12 inches on the interior of the panel. On the right a stronger nailing pattern consists of nails spaced at four inches around the perimeter and six inches in the center of the panel.

EXAMPLES OF ROOF SHEATHING FAILURE

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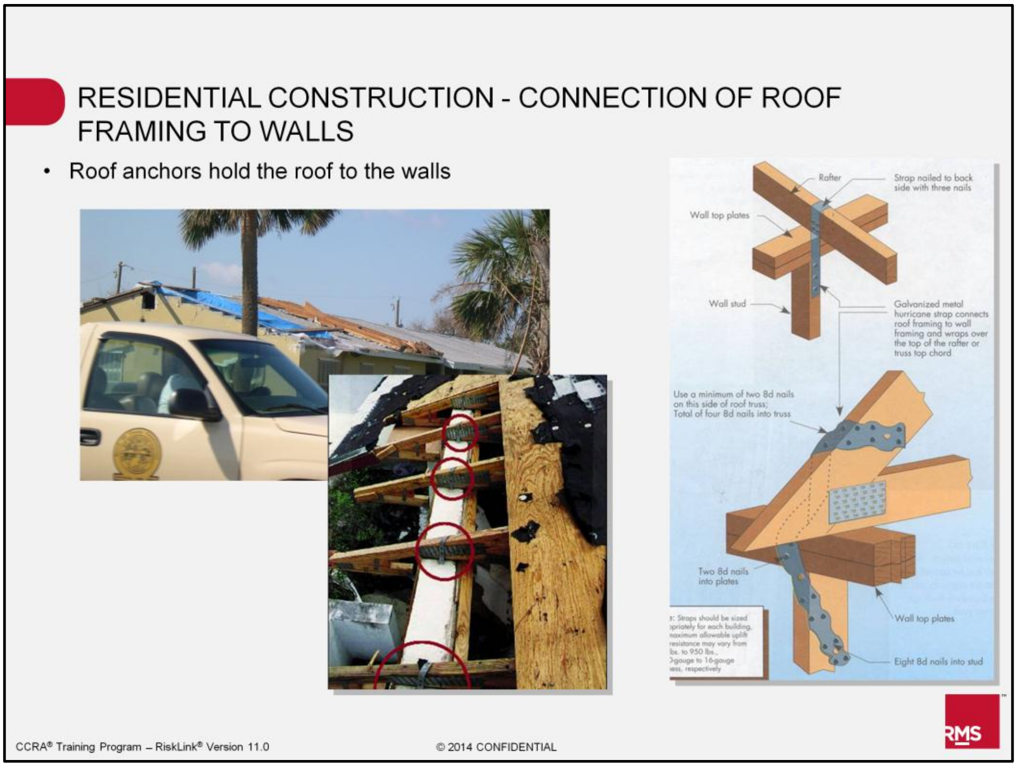
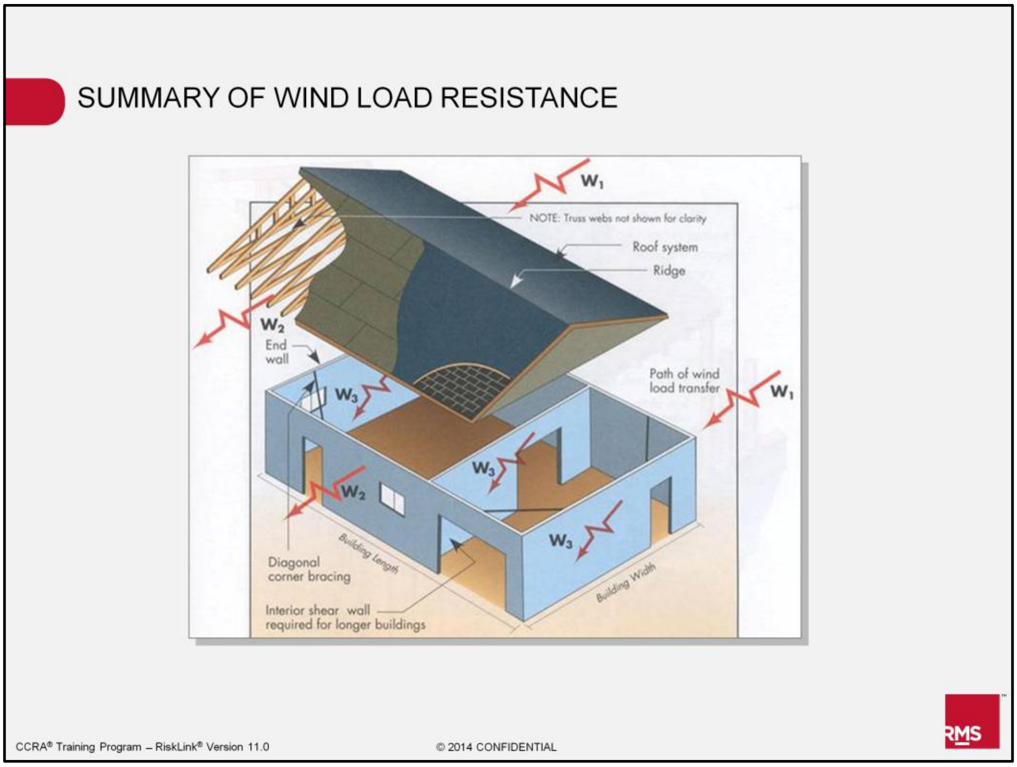
These photos show an assortment of roof damage. The left photo shows roof sheathing that has been removed in various locations. The right photo shows sheathing that was removed from one section of the roof. It appears there could have been a skylight here that may have precipitated the damage.



The sheathing shown in the previous slides is attached to roof trusses, which are in turn supported on top of the wall framing. In order to prevent the roof truss from uplifting, it is attached to the top of the wall with a strap, circled in red in the photograph. In the upper photo, it looks like a complete section of the roof, including the roofing, sheathing, and roof framing, was uplifted.



In summary, a residential building must be interconnected so that a load path exists from the roof to the foundation. Roof covering must be attached to sheathing, the sheathing attached to the roof trusses, and the roof trusses attached to the wall, all with connections that prevent uplift due to suction forces. The wall studs must also be anchored to the foundation to prevent uplift as well as resist horizontal-acting wind forces.

At the beginning of the presentation, the topic of how a breach of the building envelope can result in increased internal pressures was introduced. Breaching of the envelope usually takes the form of broken windows or damaged doors. Installing window shutters and strengthening the garage doors can prevent this type of damage.

Window shutters can take many forms, from permanent, engineered metal shutters to self-installed plywood. Permanent, engineered shutters will be able to protect against larger winds, but self-installed plywood can still be effective against small to moderate hurricane winds.

MANUFACTURED HOUSING

- Design of Manufactured Housing is governed by HUD requirements.
- Changes to the HUD requirements in 1994 (post Andrew) resulted in much improved performance in the hurricanes of 2004.

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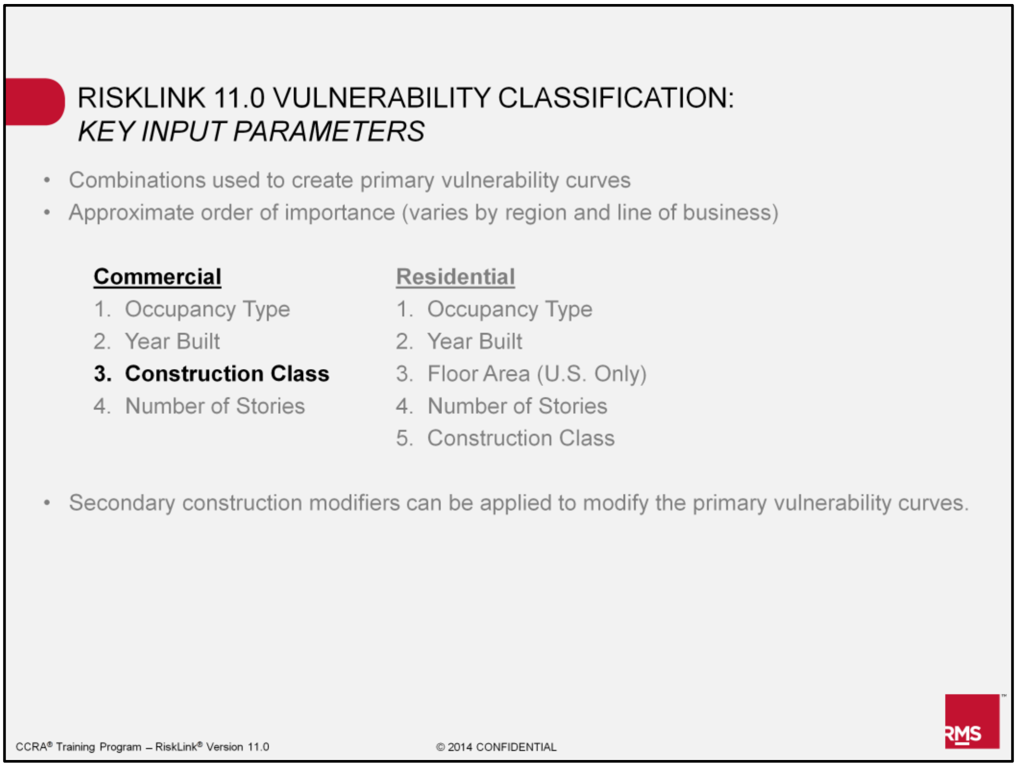
In the United States, manufactured homes (more commonly known as mobile homes) are subjected to Housing and Urban Development (HUD) design requirements that do not come under the same regulations as site-built homes that must meet statewide building codes. The HUD code has undergone two significant changes during the last 30 years. The first was in 1976 when wind design requirements were incorporated into the regulations. The second was in 1994 when the wind requirements were made much more stringent. This change was in response to the damage incurred during Hurricane Andrew in 1992.

Based on field observations found in the 2004 hurricanes, as well as reviews of claims data, it is apparent that manufactured homes built post-1994 performed much better than homes built prior to that date. Manufactured homes built prior to 1994 performed very poorly, as has been the case in prior hurricanes.



The next set of slides cover the topic of commercial construction class – one of the primary construction characteristics listed above.

COMMERCIAL STRUCTURES WIND VULNERABILITY

- For small commercial properties with wood roofs, issues are similar to residential construction.
- For larger commercial buildings, roofing, window protection, and cladding are the major determinates of building performance.

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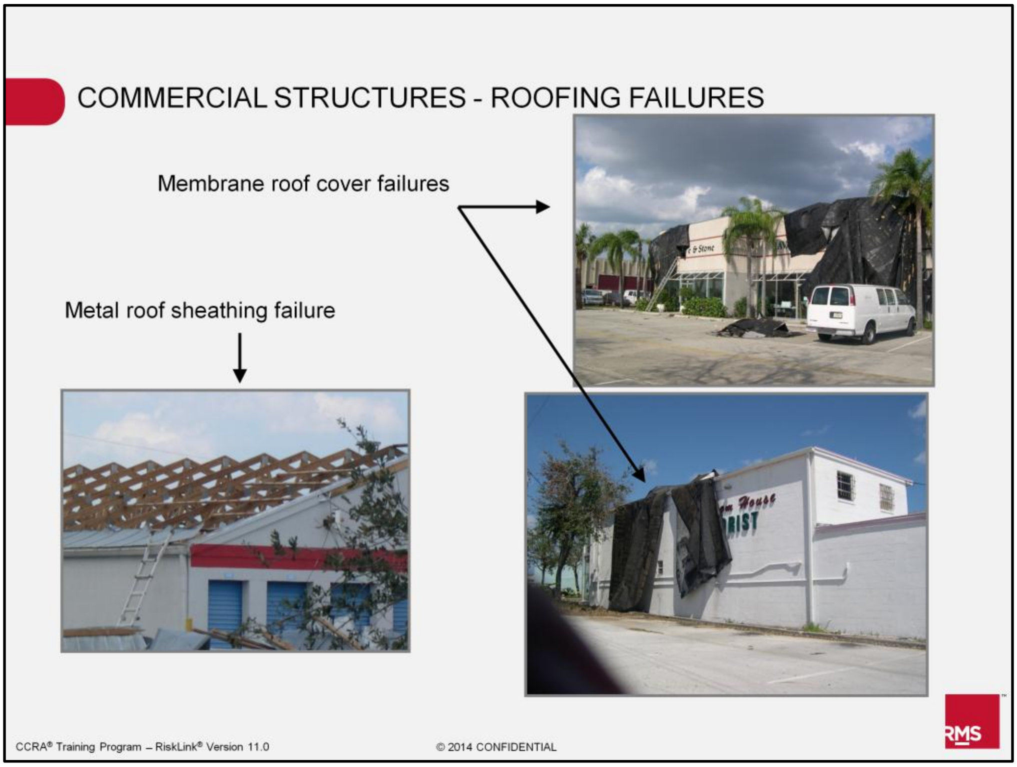
We will now turn our attention to commercial construction. For smaller commercial properties with wood roofs, such as shown in the top photograph, the issues are similar to residential construction. For larger commercial buildings, roofing, window protection, and cladding are the major determinants of building performance.



Whereas most residential roof coverings are shingles or tiles, there is more variety in the types of roof covering seen on commercial buildings.

The photographs on the right show membrane roofs that have been peeled off in the hurricanes of 2004. These coverings are often found on flat-roof buildings and, if not attached adequately, are susceptible to uplift. Damage can also often be initiated at the flashing along the perimeter of the roof where the wind forces are the greatest. In addition to the cost of replacing the roof, rain infiltration can result in extensive losses.

In the photograph on the left, the warehouse roof has been stripped of all metal panel sheathing that was not adequately anchored to the roof trusses that are still standing.

COMMERCIAL STRUCTURES – ROOF TYPE STEEL/RC

- Concrete and steel frame buildings are now modeled using the same vulnerability functions (but different than light metal). The building envelope is much more important than the structural frame.
- Vulnerability of concrete/steel buildings with a light metal/wood roof vs. a concrete roof is now explicitly differentiated.

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In the U.S. Hurricane model, four generic construction classes are identified for building exposures: wood frames, masonry frames, reinforced concrete or steel frames, and light metal frames. Observations from the insurance claims data and recent hurricane field reconnaissance reports on the performance of reinforced concrete and steel frame buildings suggest that those two frame types perform fairly similarly under hurricane wind forces if the roofing systems are the same. For example, the performance of a reinforced concrete frame structure is similar to the steel frame structure if both buildings have cast-in-place reinforced concrete roofing systems. Therefore, the vulnerability of reinforced concrete and steel structures are now distinguished depending on their roofing system. Two roofing systems are identified: reinforced concrete roof decks and metal or wood roof decks. It is worth noting that in the U.S. Hurricane model, reinforced concrete or steel buildings with concrete roof decks are less vulnerable than reinforced concrete or steel buildings with steel roof decks.

In cases where the roof type of a reinforced concrete or steel building is not identified, the inventory database will be invoked and a weighted average of the vulnerability functions for buildings with concrete roof decks and buildings with wood/metal roof decks will be estimated for the building. The weight factors will be chosen from the inventory database and are a function of the building height. In other words, low-rise buildings are weighted more toward the wood/metal roof deck class and high-rise buildings are weighted toward the concrete roof deck class.

COMMERCIAL STRUCTURES - OPENING PROTECTION

- Opening protection systems can greatly reduce the probability of window damage and wind driven rain entering the building.

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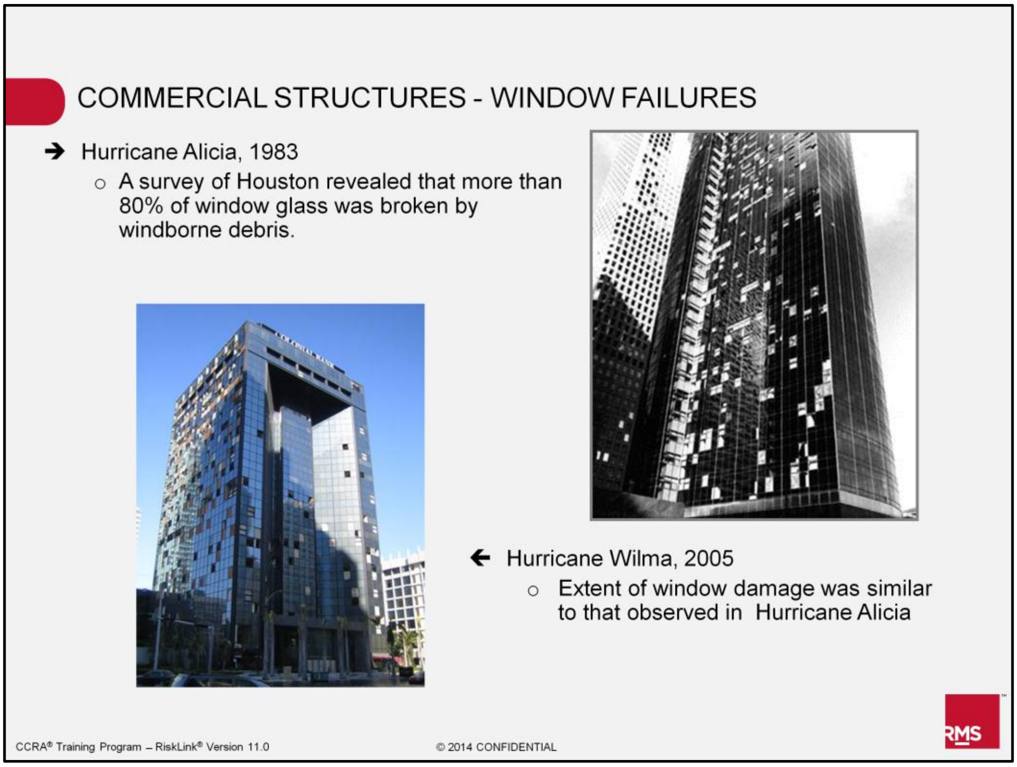
Another area of vulnerability for commercial and multi-family structures is window penetrations. Especially for beach front locations, a majority of the exterior of a building can consist of window openings. If those openings are breached, rain-driven damage can be significant. In the photographs it can be seen that these buildings have shutter systems to protect the windows and, in addition, encompass open balcony spaces.



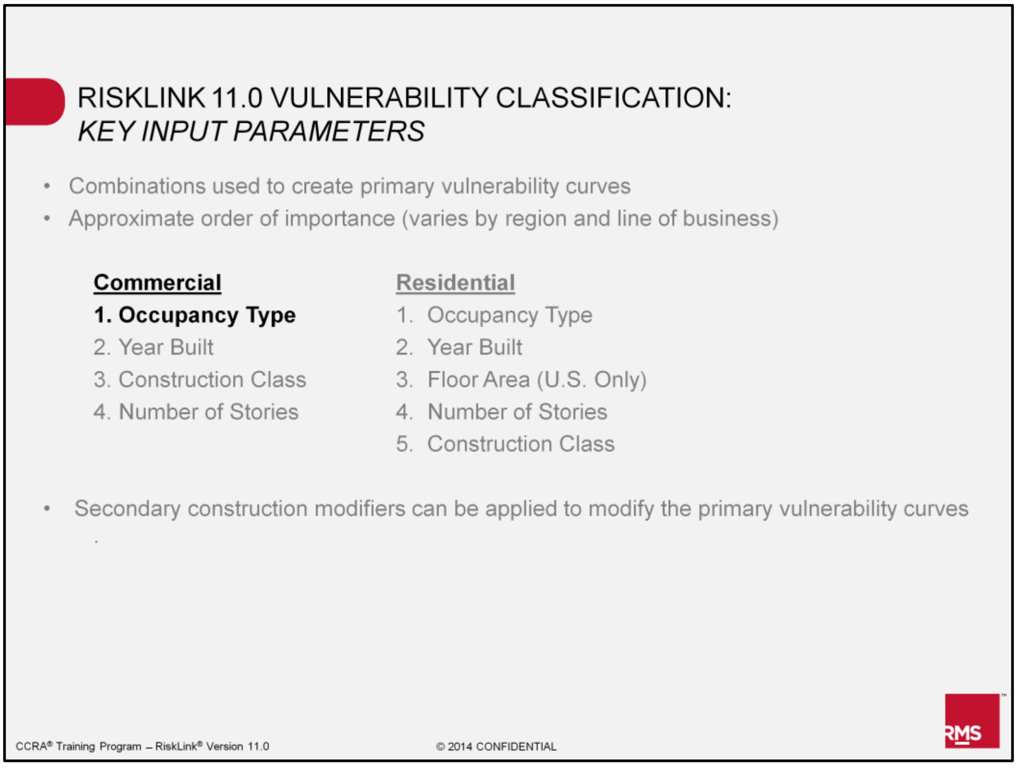
This slide illustrates some examples of window damage in high-rise buildings. Hurricane Alicia showed that wind-borne debris can cause significant damage to exterior window systems. Gravel roofs on nearby buildings provided the missiles that caused window damage.

In the lower left is an example of window damage in Hurricane Wilma. The observed window failures were similar to those in Hurricane Alicia more than 20 years earlier.

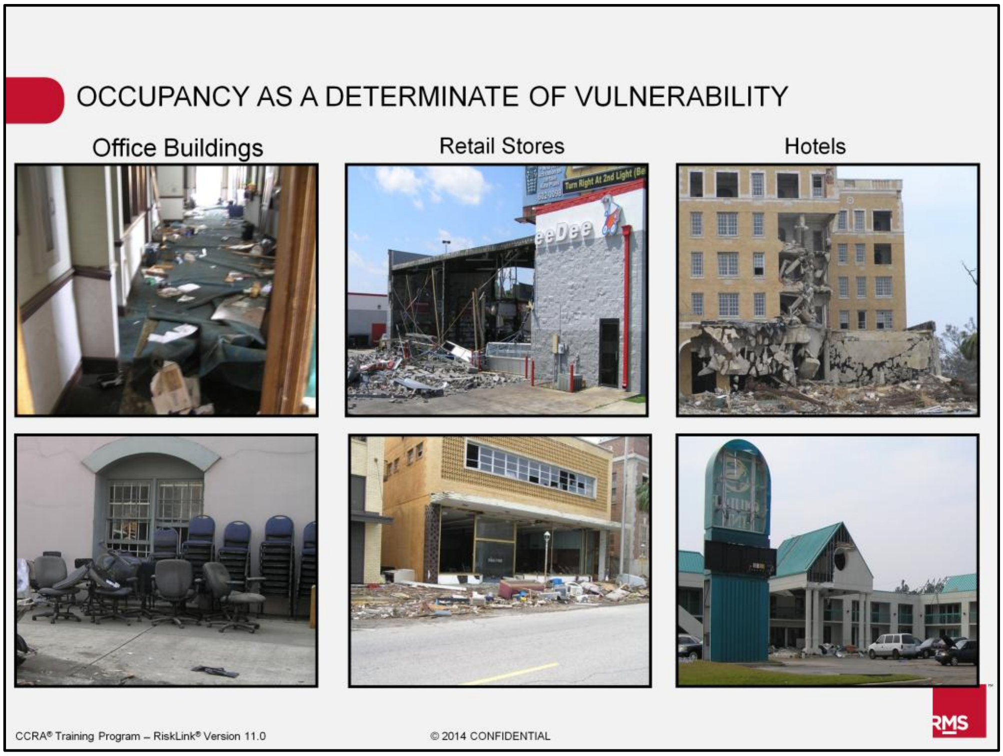
Besides roofing and windows, the next major area of vulnerability for commercial buildings can be the wall cladding, or exterior wall covering. Cladding damage is usually associated with two building materials, metal or exterior insulating and finish systems (EIFS). The photo on the lower left shows an example of exterior metal sheathing (or cladding) that has been removed from a building. This type of siding is common in industrial and warehouse occupancies.

The two photos on the right show damage to EIFS. These exterior systems can look like concrete from the outside but actually consist of a system of insulation and base and finish codes attached to a plywood substrate.

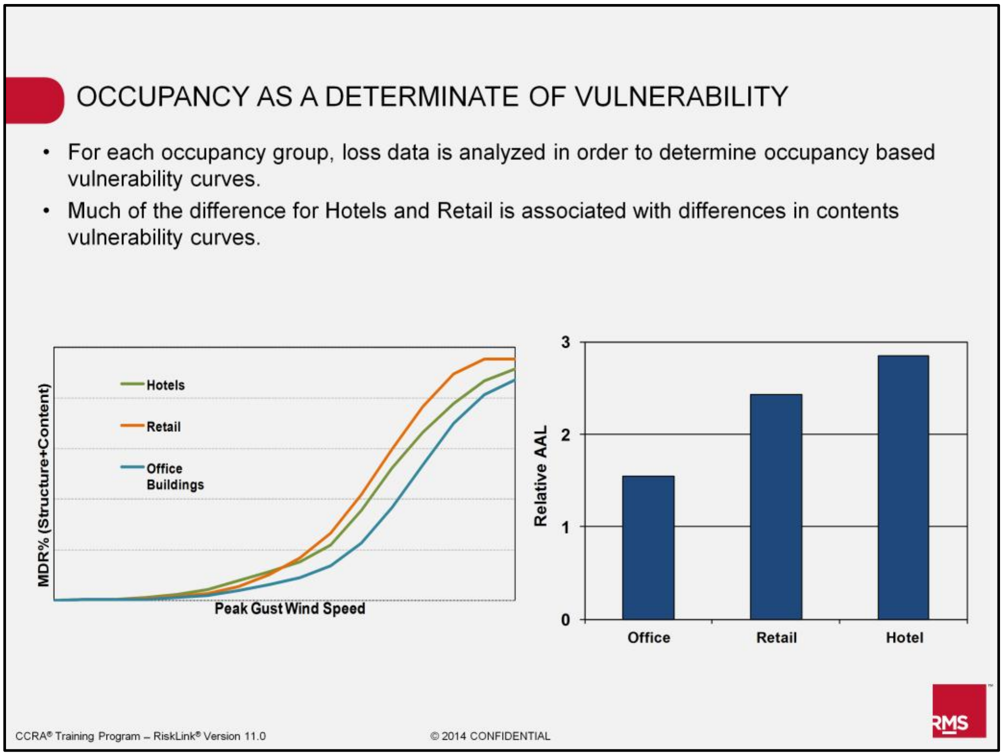
As seen in the photographs, large chunks of the exterior system have been removed, resulting in extensive interior water damage.



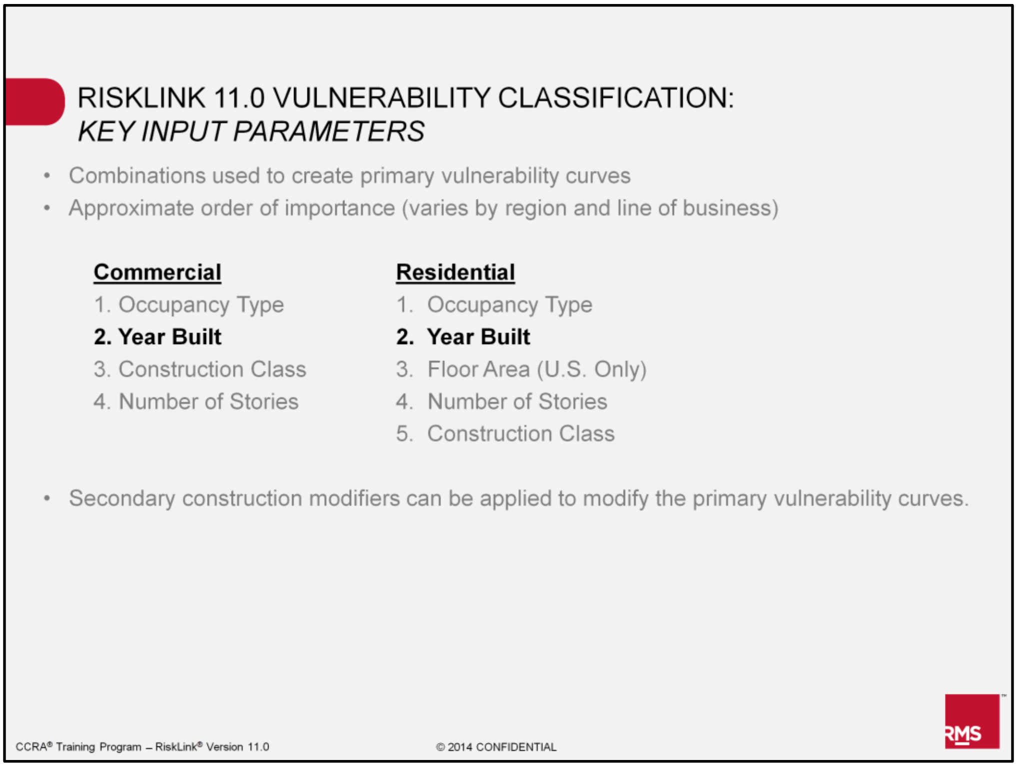
The next set of slides cover the topic of commercial occupancy type – one of the primary construction characteristics listed above.



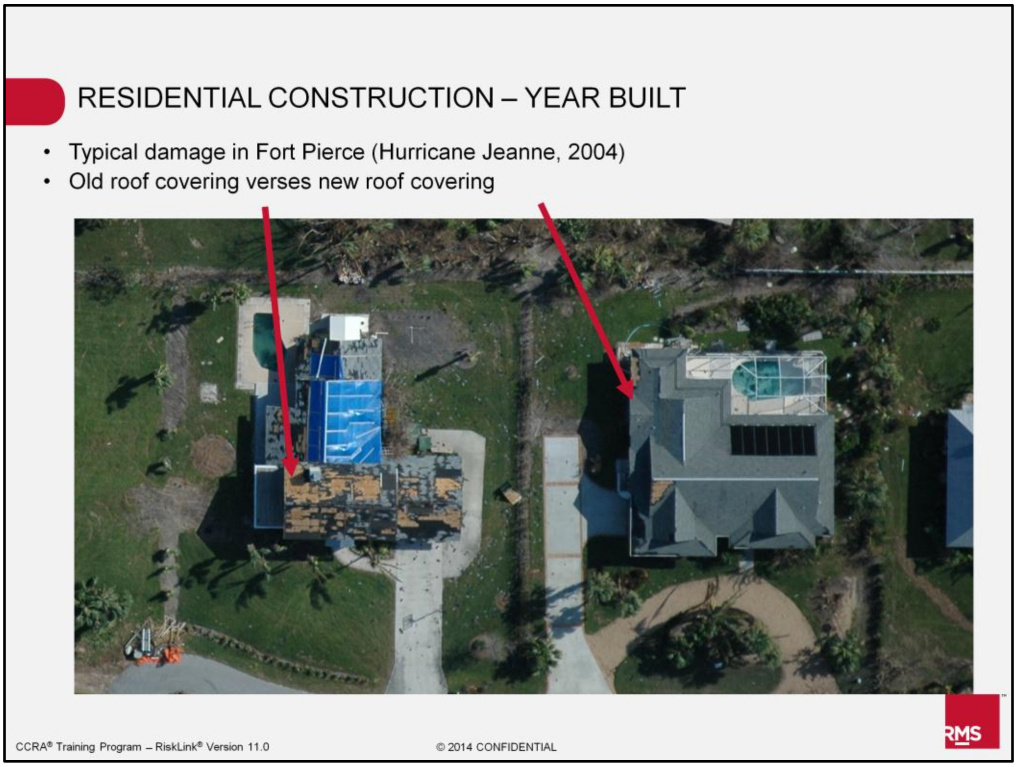
As explained previously, the results from our detailed investigation of the insurance claims data suggests that the type of occupancy is the most important factor in estimating hurricane losses. As a result, vulnerability functions developed for the U.S. Hurricane model vary significantly for various types of occupancies. For example, on average, buildings in the temporary lodging (hotels) occupancy class are 75% more vulnerable than office buildings. Therefore, it is important for RiskLink users to code the appropriate occupancy type to obtain a reliable estimate of their portfolio risks.



Claims data support the fact that hotels are more vulnerable than retail occupancies and retail occupancies are more vulnerable than office buildings due to the type and value of contents coverage.



The next two slides cover the topic of age of construction – one of the primary construction characteristics listed above.



The age of a building is a significant factor in differentiating building performance. The above photograph of two side-by-side structures provides such an example. The older roof has experienced much more damage. Notice that the damage to the roofing of the newer house is localized around the exterior edges of the roofing, again, where the pressures are highest.

RESIDENTIAL CONSTRUCTION – YEAR BUILT

- Burnt Lakes Area Comparison (Hurricane Charley, 2004)

15 years old

1 year old

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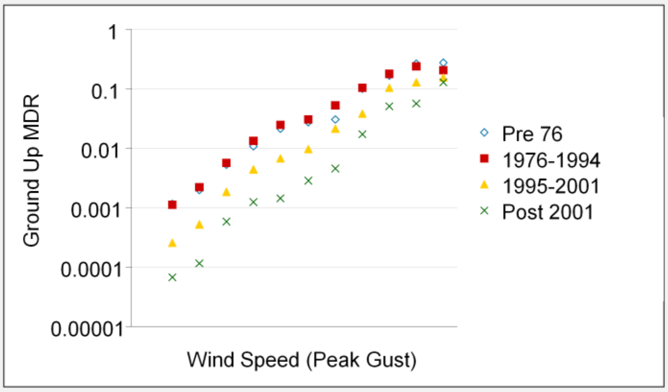
Observations from the hurricanes in 2004 have shown that the more stringent building codes have, indeed, made a difference in the performance of buildings. RMS performed field reconnaissance following storms in the 2004 and 2005 U.S. hurricane season and consistently observed better performance for newer housing. The newer buildings, in addition to being designed to more stringent codes, will have experienced less aging due to sun exposure and other environmental conditions.

IMPORTANCE OF YEAR BUILT

- Comparison of claims data sorted by year band for Masonry, Vulnerability Region 2



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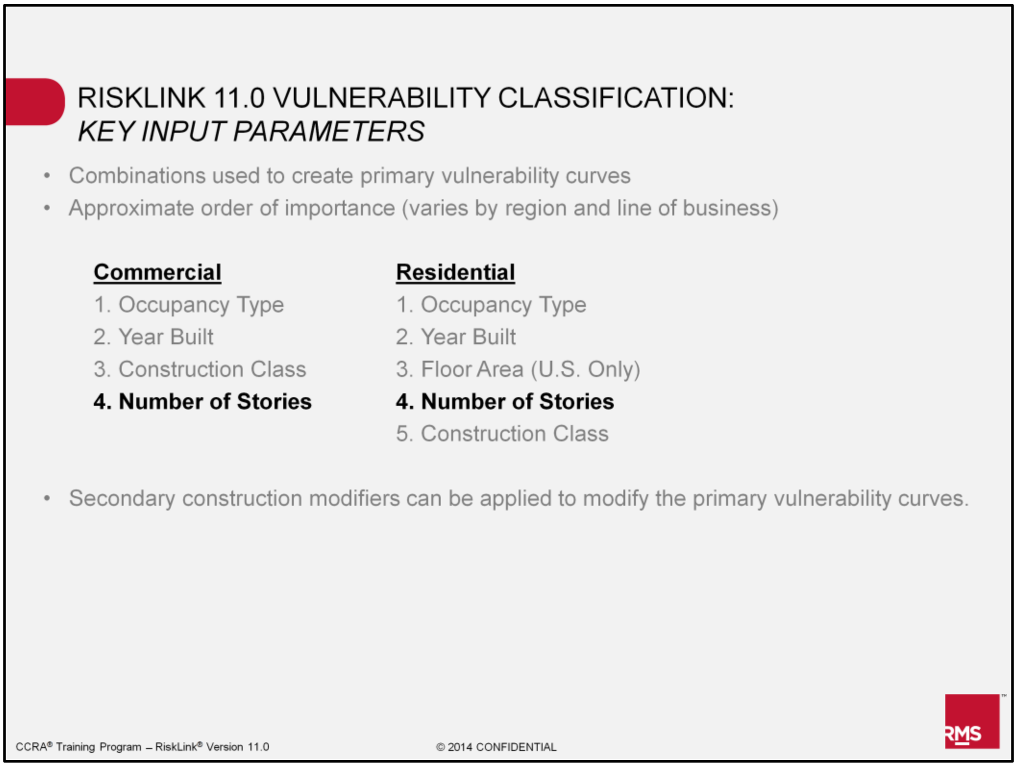
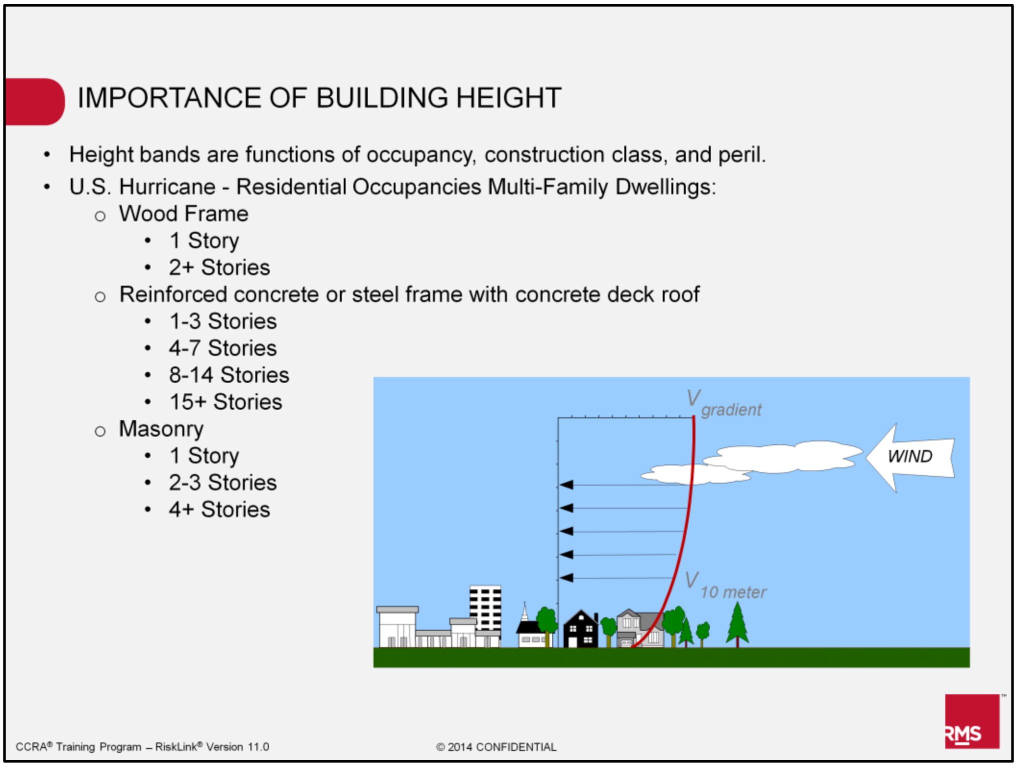
Based on the U.S. 2004 and 2005 hurricane season claims data, there is a significant variation in damage ratio between year built bands. This is predominately due to the changing building code in Florida.



The next slide covers the topic of building height, which is measured by the number of stories and is one of the primary construction characteristics listed above.

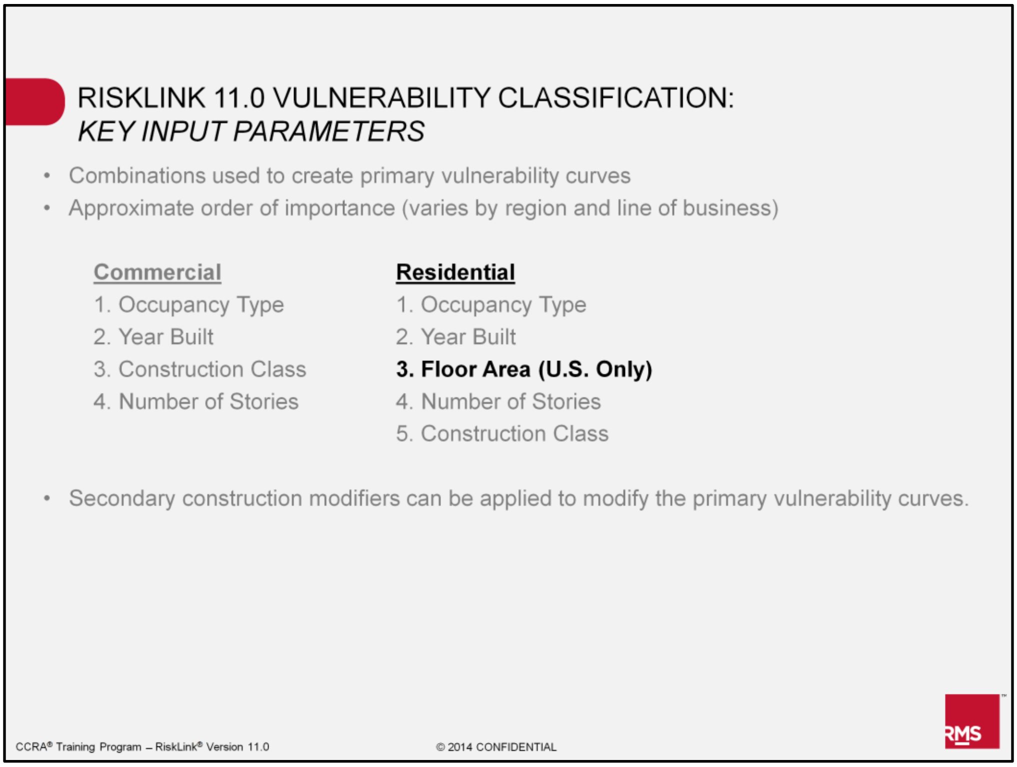


Now that we have covered the occupancy type, construction class, and year built of the building, let's turn our attention to the building height, which is measured by the number of stories. In general, vulnerability curves are functions of building height so it is beneficial to specify the building height. Fortunately, a building's height is not as difficult to define as its construction class or occupancy.

The height bands in RiskLink are functions of the occupancy, construction class, and peril. This slide lists the different height bands supported in the U.S. hurricane model for residential occupancies (multi-family dwellings) of various construction classes.

For hurricane wind losses, all buildings within a given height band are treated as if they are the same height. Consequently, for a wood frame single-family residence, the vulnerability curves associated with one and two story buildings will be different but the vulnerability curves associated with two and three story buildings will be the same. However, this is not true for other perils; for example, for storm surge, the vulnerability curve decreases with each additional story specified. Consequently, you should always enter the exact number of stories.

Detailed information about the height bands implemented in the RMS vulnerability modules can be found in the RMS model methodology documents on www.rms.com.



Next we will cover the topic of building floor area, one of the primary construction characteristics listed above for residential risks.

RESIDENTIAL BUILDING FLOOR AREA – U.S.

- As the floor area of residential buildings increases, the mean damage ratio decreases.
  - Ratio of damaged area of building to the total area tends to be smaller on average for larger buildings.
  - Larger buildings tend to have a general improvement in construction material and quality.

Floor Area Ranges
≤ 1,506 sq. feet
1,507 – 2,507 sq. feet
2,508 – 5.005 sq. feet
5,006 – 10.010 sq. feet
≥ 10,011 sq. feet

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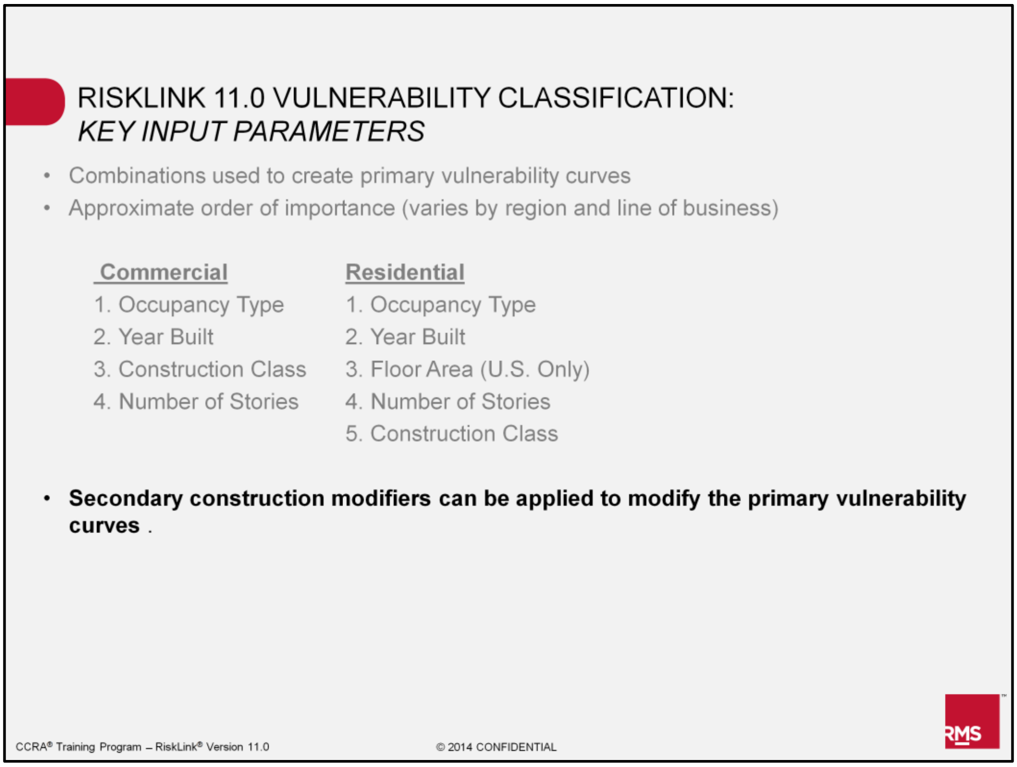
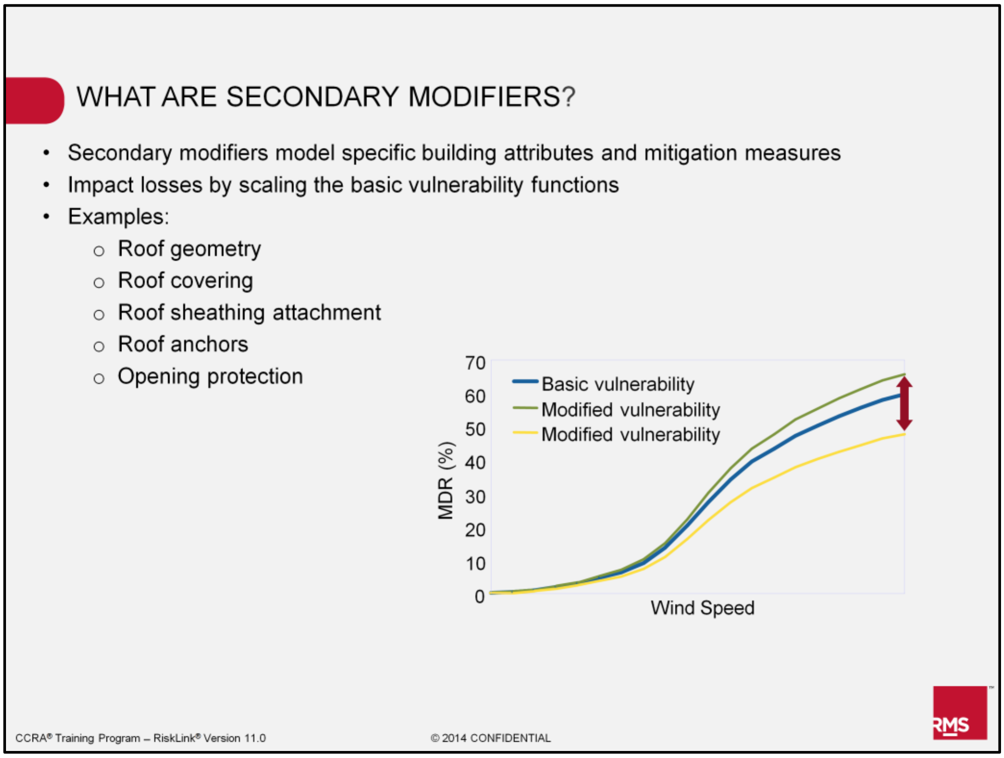
Based on residential claims data, RMS has observed a clear relationship between the mean damage ratio and the floor area of residential buildings. As the floor area increases, the mean damage ratio decreases. The dominant factor in this relationship is the ratio of the size of the highest suction zones created by the wind to the total surface area of the building. The high suction zones on a building are created by vortices that form at sharp edges on the building, such as eaves and corner walls. Although the size of these zones increase with overall building size, the rate at which they increase is not linearly related to the increase in the total building envelope area. Thus, the ratio of the damage areas to the total area tends to be smaller on average for larger buildings. In addition to this mechanism, the floor area effect can also be attributed to a general improvement in the material and construction quality for larger buildings.

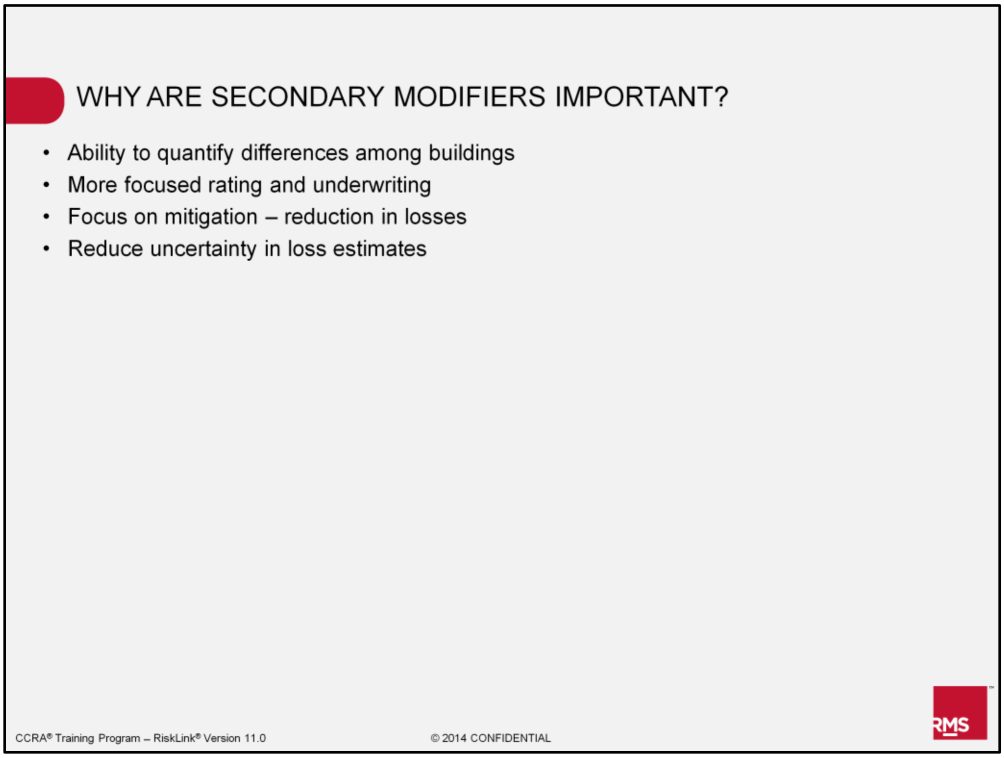


The next few slides cover the topic of secondary construction modifiers.



In the first section of the presentation the influence of specific building characteristics, such as roof sheathing, nailing, and opening protection, on the performance of a building in a hurricane were mentioned. These characteristics are examples of secondary construction modifiers. In general, the primary building characteristics (construction class, occupancy, height, floor area, and age) are the characteristics most easily determined for a given location. However, if a more refined and detailed risk assessment is desired, secondary modifiers can be utilized.

Secondary modifiers are modeled by scaling the vulnerability curves up or down, depending on the modifier. This is illustrated in the graph. The solid blue line is the basic vulnerability curve, the solid green line is a vulnerability curve modified by characteristics that degrade the performance of the building, and the solid yellow curve is a vulnerability curve based on applying the modifiers that improve the performance of the building. Examples of modifiers are the roof geometry, roof cover, roof sheathing attachment, and roof anchoring. For residential sites, some modifiers describe the hurricane damage mitigation measures that are recommended or required in some hurricane states.



So why are secondary modifiers important? First, they provide the ability to quantify differences in building construction that would impact the expected building performance at a given wind speed. This in turn allows for the development of more detailed rating and underwriting guidelines. Very importantly, they can be used to quantify the impact of the application of wind damage mitigation measures, such as adding shutters to a building. And, finally, they reduce the uncertainty in modeled loss estimates.

DEVELOPMENT OF SECONDARY MODIFIERS

- Modifiers are based on:
  - Engineering studies and field observations
  - Peer-reviewed scientific studies and publications
  - Building code guidelines
  - Claims data and damage statistics
- Secondary modifiers impact losses for some building types more than others.
  - Roof Geometry: Greater impact on low-rise buildings than on mid- and high-rise buildings
  - Roof Anchors: The toe-nail / no anchorage option only affects low-rise construction – for mid- and high-rise buildings some form of roof-wall anchorage is always present.

How are secondary modifiers developed? Empirical development of secondary modifier impacts on losses is limited by lack of claims data availability. For example, in past hurricanes, post-event claims data has rarely included information on building-specific characteristics, such as whether shutters were present or information on the geometry of the roof. Therefore, we cannot rely on claims data and damage statistics alone to the quantify of the impact of secondary building characteristics.

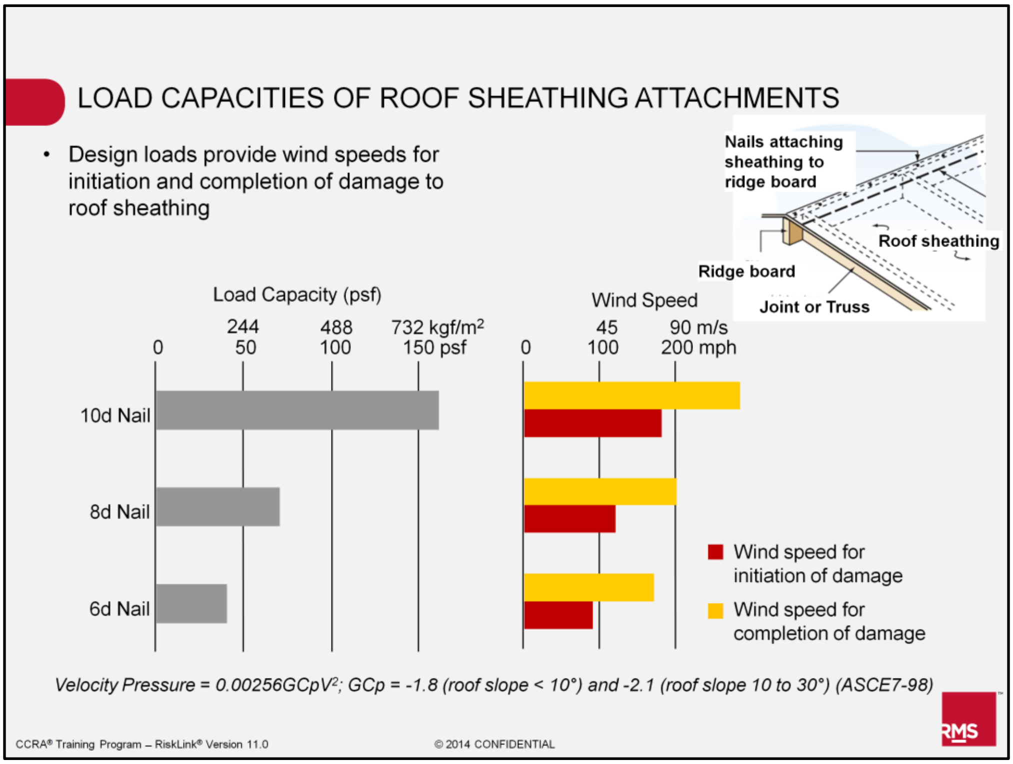
We primarily consider published engineering studies that examine the impact of various building components on a building's hurricane performance. For example, there have been a number of studies performed to determine the resistance for different types of roof anchors. We incorporate the results of those studies into our models through the use of analytical component-based models.

We also consider the results of wind tunnel experiments that are done by the general wind engineering research community and give an indication of what loads can be expected based on different aerodynamic shapes of different buildings. Furthermore, we review the history of various building codes and the features that are built into each one in different parts of the country that we use as guidance for developing our secondary modifiers.

And lastly, we examine any available claims data and damage statistics after each major event to better understand how different secondary characteristics affect the performance of buildings and validate the implemented modifier values. For example, we may examine claims data to quantify the performance of buildings with hip roofs versus those with gabled roofs and compare these empirical results to the implemented secondary modifiers for these two roof geometries. However, as indicated above, such claims data is limited and cannot be relied upon solely to derive the secondary modifier values.

Secondary modifiers impact losses for some building types more than others. For example, the roof geometry has a larger impact on low-rise buildings than it does on mid- and high-rise buildings due to the wider variety of roof shapes on low-rise buildings and the reduced influence of the roof shape on the wind pressures experienced by a building as the building height increases.

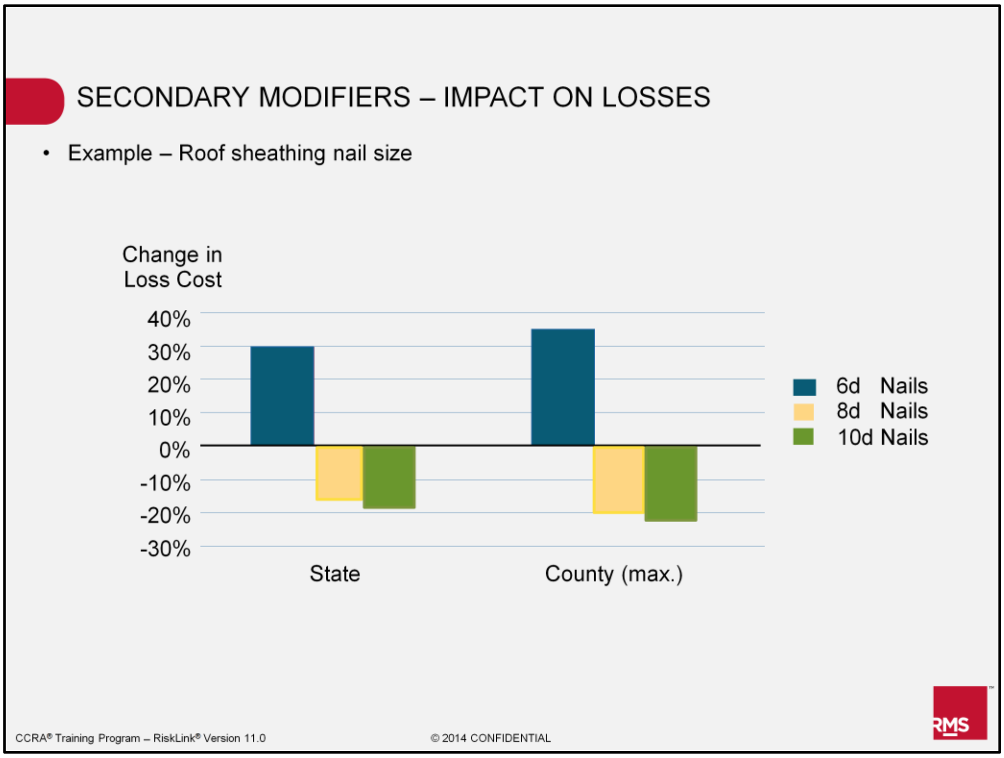
Another example is roof anchors where the toe-nail / no anchorage option only has an effect on low-rise construction, because this condition does not exist in mid- and high-rise construction. In mid- and high-rise construction, there will always be some form of roof-wall anchorage since such buildings are engineered.



This slide illustrates an example of quantifying the impacts for the roof sheathing attachment modifier. The roof sheathing is the wood deck under the roof covering. Keeping the roof sheathing intact is important for mitigation of losses during a hurricane. The length and diameter of nail used is a critical factor in determining whether the roof sheathing will resist the wind uplift forces acting on a building.

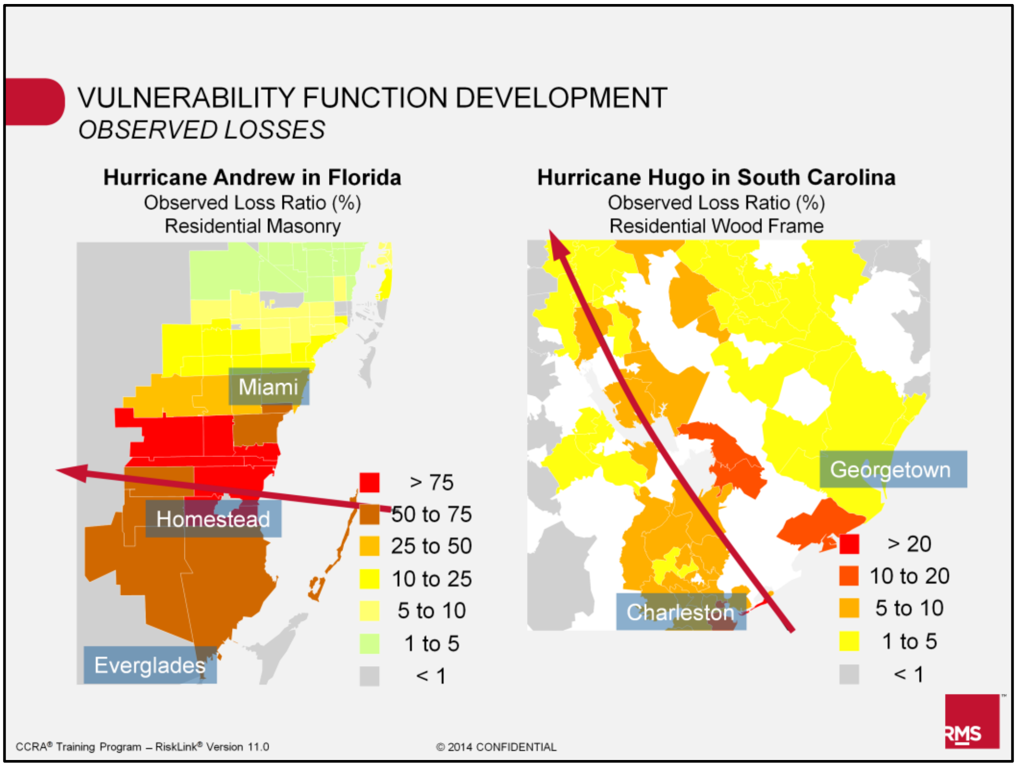
In the absence of claims information, an analytical approach is used whereby engineering studies, wind-tunnel experiments, and field observations are used to assess the uplift capacity of different nail diameters. On the left is a graph showing the design load capacity (in pounds per square foot or kilogram force per square meter) for 10d, 8d, and 6d nails. The 8d, or 8 penny, nail is a designation of the length and diameter of the nail, so a 10d nail is larger than a 6d nail. The design load is the maximum force that can be applied to the nail before it fails or is forced from its position.

These resulting load capacities are converted to equivalent wind speeds that are then utilized to determine the component strengths for roof sheathing components (shown in the upper right figure). In this example for the 8d nail, initiation of damage starts at just over an equivalent wind speed of 100 miles per hour and complete damage at 200 miles per hour. The component vulnerability of the roof sheathing is then combined with other components to define overall building performance.



This chart shows the impact on average annual loss for different sheathing attachment conditions. These values are relative to the unknown or average case, which lies between the 6d and 8d nail size cases. This sensitivity analysis was run for a Florida statewide portfolio. The average statewide and county maximum impacts are shown.

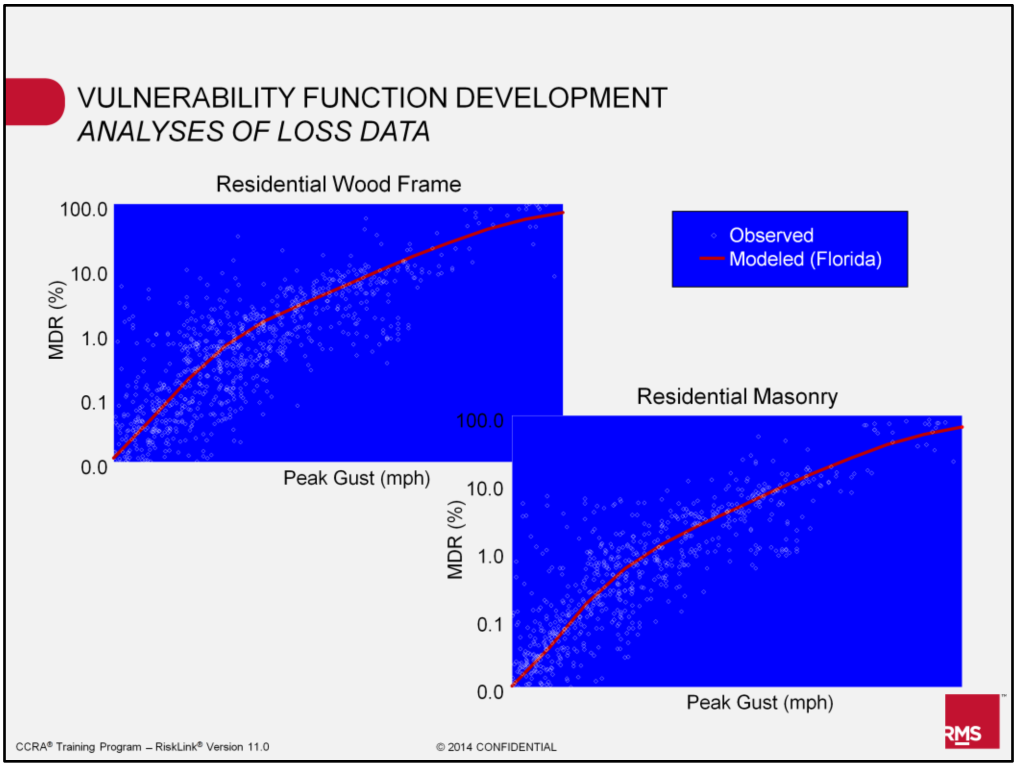
If we look at the statewide results, for example, if instead of specifying an unknown roof nailing condition you specified 6d nails, the change in loss cost average on a statewide basis would increase 30%. However, if you specified either 8d or 10d nails, which is stronger than the average condition, then the overall statewide loss cost would reduce approximately 15-18%. The results for the maximum county changes within the state of Florida are relatively similar to the statewide changes.



The vulnerability classification scheme that has been presented provides the context for describing the methodology for developing vulnerability functions. There are two primary inputs to the development of vulnerability functions: empirical loss data and analytical models.

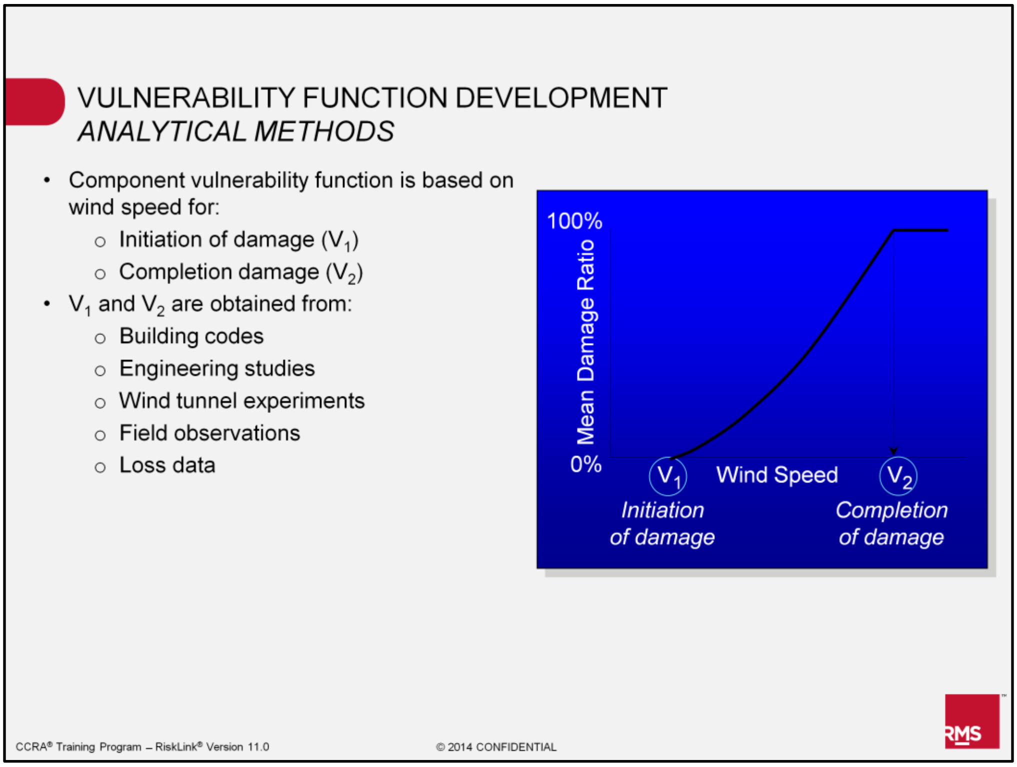
Empirical loss data: When available, vulnerability functions are calibrated using actual insurance claims data. Therefore, following significant events, RMS gathers as much data from clients as possible. This was particularly relevant following the 2004 and 2005 hurricanes, which resulted in a large claims review process.

Analytical models: The graphics on this slide show observed losses for Hurricanes Andrew and Hugo. In both cases, an extensive amount of insurance loss data was compiled in order to calibrate vulnerability curves. The first task in calibrating the loss data is to create a reconstruction of the wind field footprint. This is accomplished by using observed wind speed recordings, as well as an assortment of meteorological data provided by the National Hurricane Center and other research organizations.



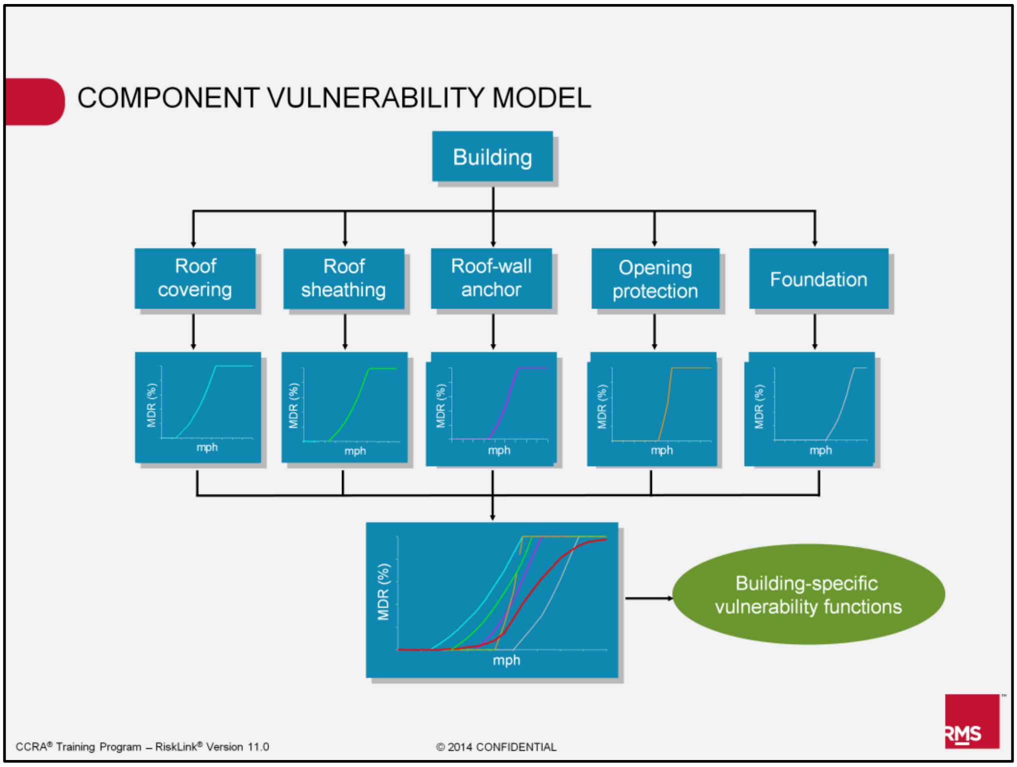
Once a wind field footprint has been developed, the observed damage ratios can be plotted as a function of wind speed for each observed location vulnerability classification. Again, the damage ratio is the repair cost divided by the coverage value. A regression analysis is then performed to arrive at an empirically based vulnerability curve (shown as the red line in each graph).

This slide shows examples for residential wood frame and masonry construction. This effort is performed for multiple storms and multiple client portfolios.



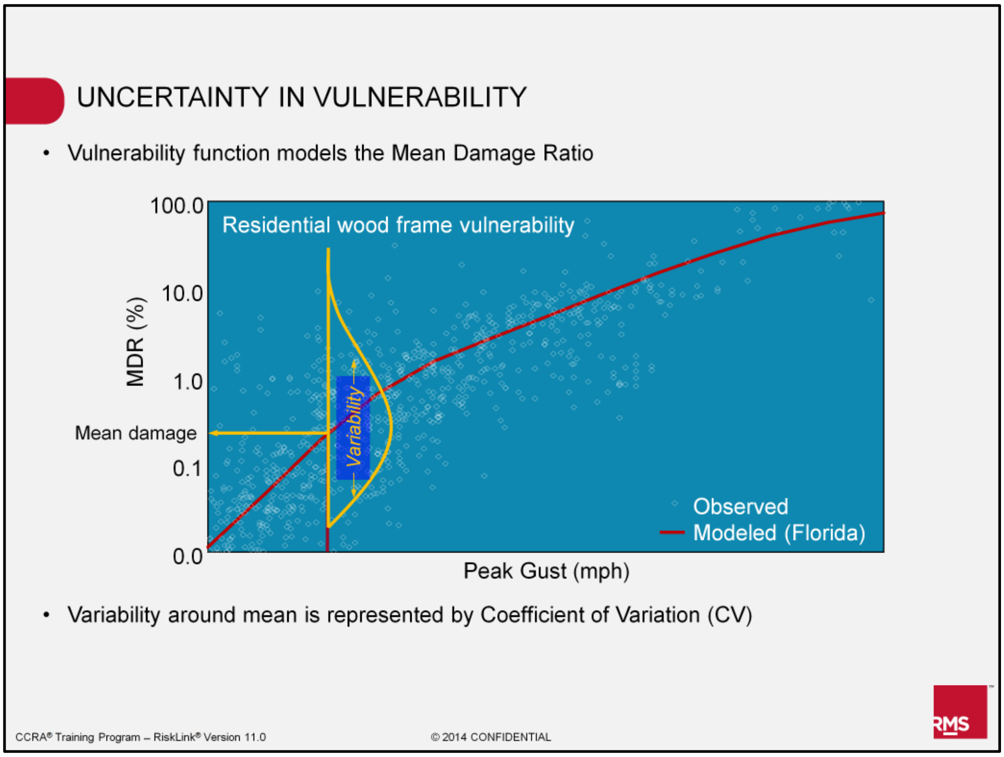
Unfortunately there is typically not enough loss data to develop individual vulnerability functions for each one of the permutations of construction material, occupancy, and height ranges previously presented. In order to fill in the gaps, we need to perform analytical studies aimed at determining relative vulnerabilities for different building classes and/or heights.

One analytical approach is the component vulnerability methodology. For each major component of a building (e.g., roof covering or roof sheathing attachment), a component vulnerability function is developed which models the wind speed where damage initiates, and the wind speed at which total damage to that component occurs. An example is shown in the graph. These wind speeds are based on building codes, engineering studies, wind-tunnel experiments, field observations, and loss data.



After the component vulnerability functions have been developed for each one of the components, they can be combined to determine an overall building vulnerability curve. These component-based curves can be compared to curves derived from empirical data, where there is sufficient loss data to provide validation and calibration of the model-based curves.

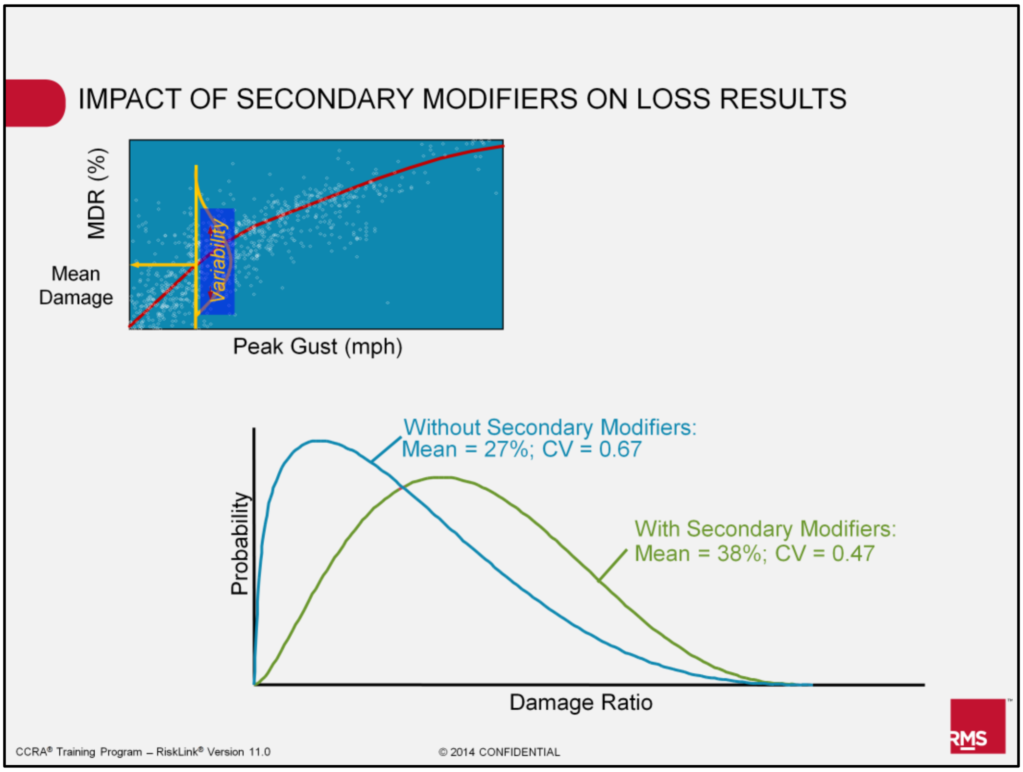
After calibration, the approach can then be extended to the development of vulnerability curves for building classes where empirical data is lacking. This component approach was introduced in the discussion of the roof sheathing attachment secondary modifier.



Again, it is using these types of analytical approaches we can refine relationships between building component capacities and their impact on overall building damage. However, it should be stressed that these analytical methodologies need to be calibrated against actual observed building performance and loss data.

Until now, vulnerability functions have been discussed in terms of the mean damage ratio or the average damage ratio at a given wind speed. As this slide illustrates, there is a significant amount of variability around the mean damage ratio at a given wind speed as characterized by the yellow curve. Quantifying this variability is very important, in particular when assessing uncertainty in modeled losses.

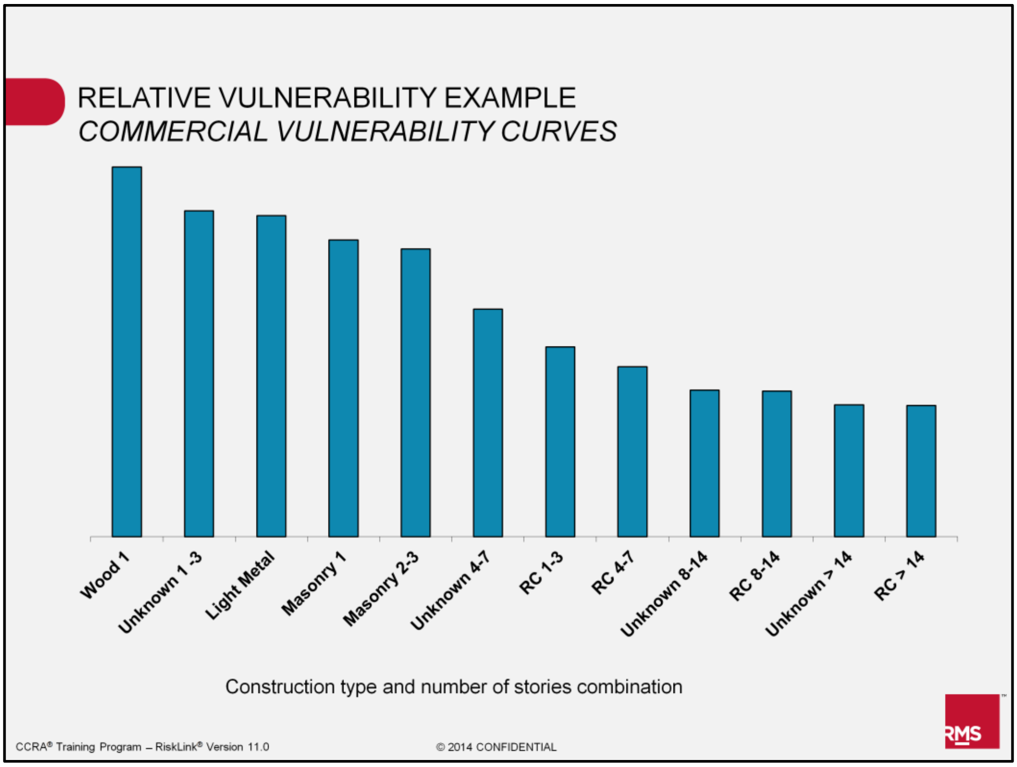
The variability around the mean is termed secondary uncertainty and is represented by statistical terms such as the standard deviation and coefficient of variation, which were introduced in the Financial Modeling and Uncertainty Measures courses.



This slide illustrates an example of the impact that secondary modifiers can have on secondary uncertainty around loss results. The upper chart is the same as previously presented, showing the variability around the mean damage ratio at a given wind speed. Some of the variability can be attributed to the fact that individual locations of the same building class and height will have different characteristics. If some of these characteristics are known, the uncertainty can be reduced.

The bottom chart illustrates the effect of applying a secondary modifier on a probabilistic distribution of damage ratios. Note that the secondary modifiers will impact the mean damage ratio value, as well as the variation around the mean. The coefficient of variation, which is the standard deviation divided by the mean, is used to provide a quantitative assessment of uncertainty.

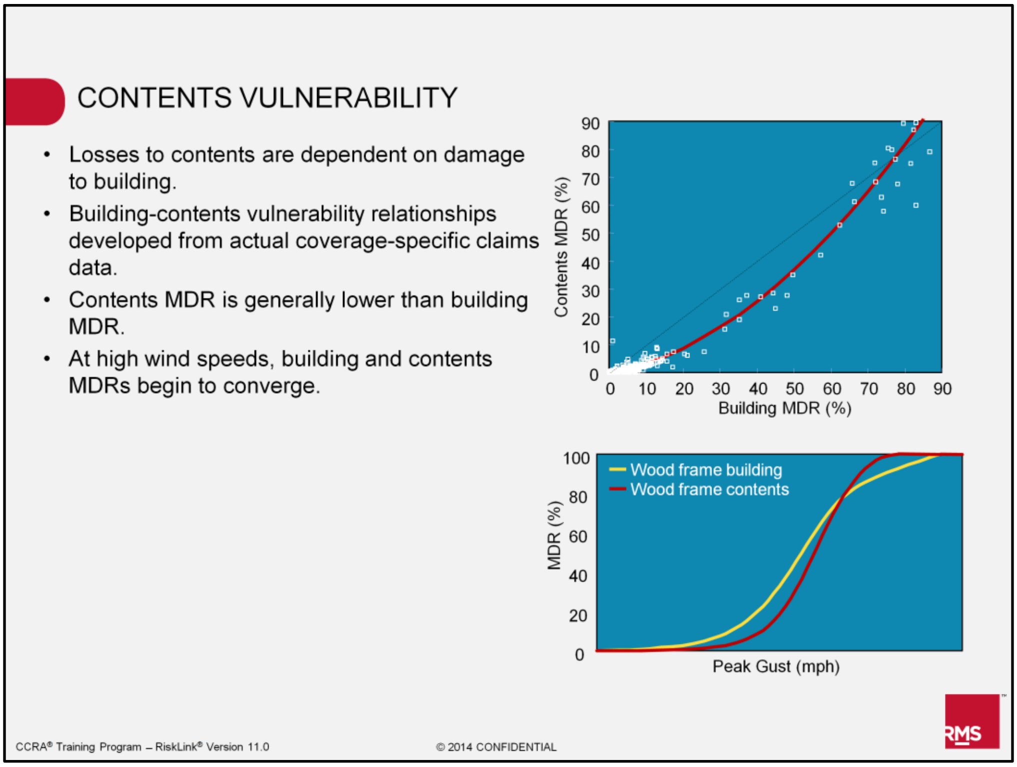
In this example, the blue curve distribution is derived from an analysis with all secondary modifiers set to unknown. The green distribution is the same property with a secondary modifier, such as poor roof sheathing nailing. Notice the mean value of the losses at this particular wind speed has increased from 27-38%, but the coefficient of variation has decreased because we provided additional information about the building.



As a means of summarizing the development process for vulnerability curves, this slide shows relative average annual loss (AAL) for different commercial construction and building heights (number of stories). The relativities are based on AAL for a specific location in Florida per unit of exposure value. In relative terms, the vulnerability of high-rise reinforced concrete buildings is the smallest, and the vulnerability of wood-frame and light metal buildings are the largest.

There are two predominant factors resulting in lower damage ratios for taller buildings. In general, taller buildings will tend to have poured in placed concrete roofs which resist wind damage better relative to other types of roof construction. Additionally, failure of the roof covering impacts a lesser percentage of the interior of the building compared to the roof cover failure on a low-rise building.

The latter factor is also important for residential buildings, where the greater the square footage of the building footprint relative to the height of the building, the less the damage. This is related to the fact that damage divided by large exposure = smaller damage ratios, and that larger homes tend to have higher quality materials/workmanship.

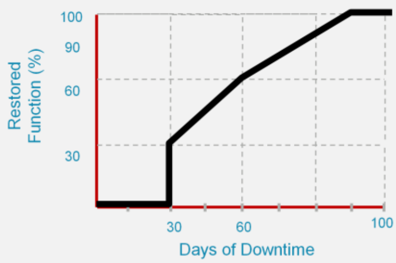


So far we have only been discussing building vulnerability, but a risk model must also include vulnerability relationships for contents and business interruption or additional living expense loss estimates.

Contents losses are dependent on the damage to the building exterior. Rain and water damage is the largest contributor to contents damage. Building contents vulnerability relationships are developed in a similar manner as was described for the building damage ratios, and use specific claims data to develop those relationships. In general, the contents mean damage ratios will be lower than the building mean damage ratios, in particular at lower wind speeds. However, at higher wind speeds, where there is greater damage to the building envelope, building and contents damage ratios tend to converge.

FACILITY RESTORATION CURVE DEVELOPMENT

- Earthquake or hurricane building damage ratio mapped to seven damage states
- For each combination of occupancy type and damage state a facility restoration curve is created



Damage State	Mean Damage Ratio Range (%)
1 - None	0
2 - Slight	0 – 0.5
3 - Light	0.5 – 5.5
4 - Moderate	5.5 – 20
5 - Heavy	20 – 45
6 - Major	45 – 60
7 - Destroyed	60 - 100

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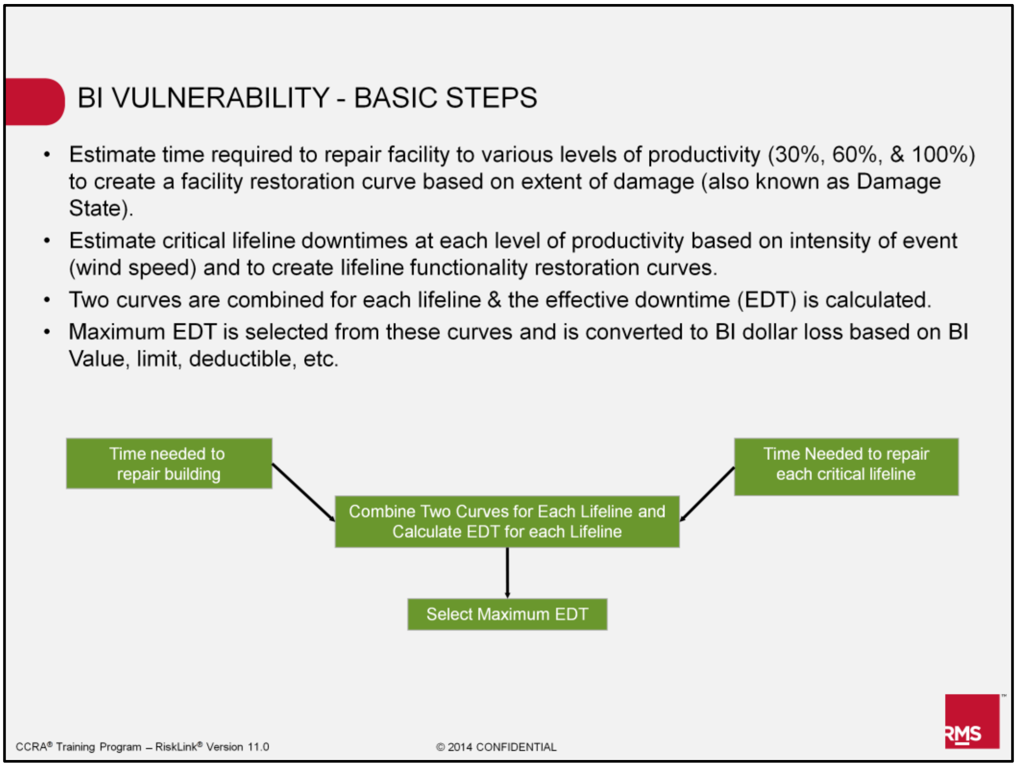
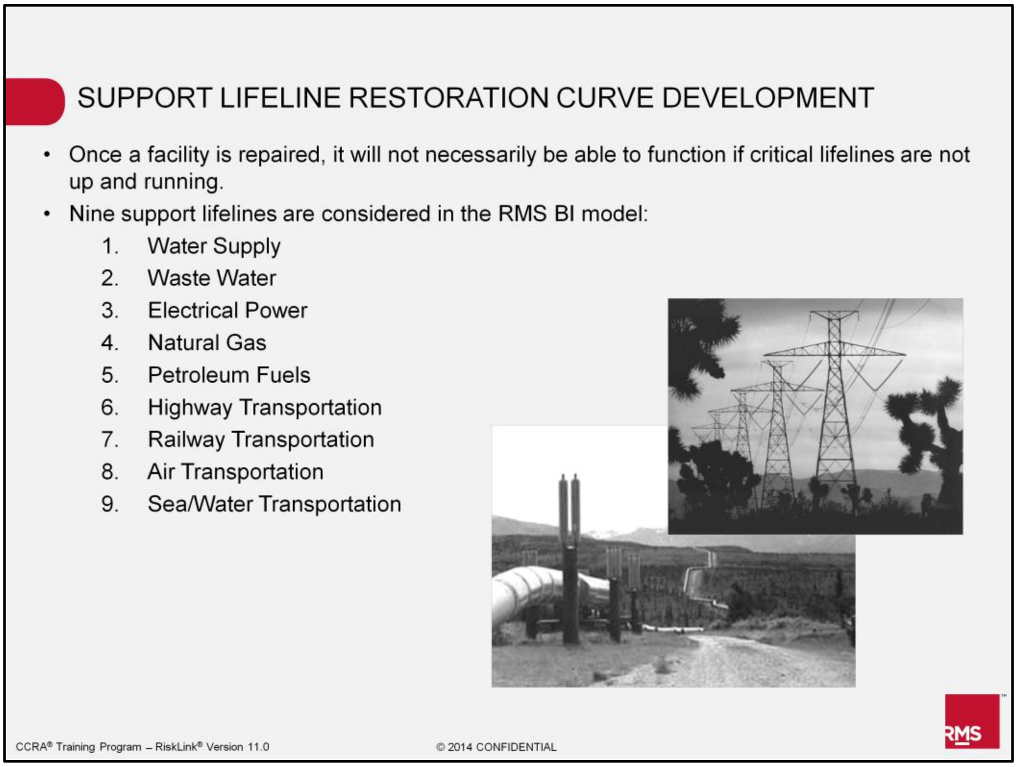
Loss of use, or business interruption (BI), loss estimates is also a function of building damage. In simple terms, on average the more a building is damaged, the longer it is going to take to restore functionality. In calculating BI losses, the building is first assigned to one of seven damage states, depending on the physical damage to the structure, as shown in the table. These damage states range from one to seven.

Then, given the damage state in a building occupancy, a facility restoration curve is assigned. The restoration curve defines the time to restore 30%, 60%, and 100% of the building's functionality. This is illustrated by the chart on the lower right.

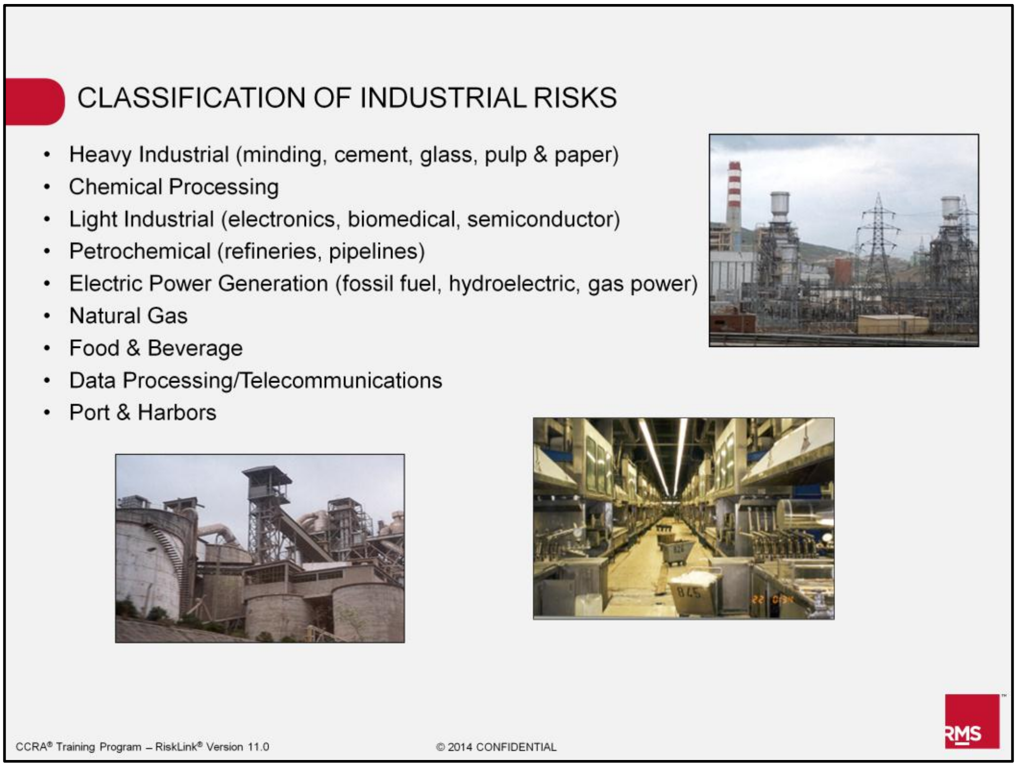


The steps in developing an overall BI relationship are first estimating the time required to repair the individual facility to various levels of productivity based on the building damage ratio and the occupancy of the facility. Next ,an estimate of the critical lifeline downtimes at each level of productivity based on the intensity of the event is made. Based on this information, a lifeline functional restoration curve is created, much as is done for the individual structure.

Then these two curves, the lifeline and the building restoration curves, are combined to determine an overall effective downtime. The maximum estimated downtime is selected from the combinations of the lifeline and building damage restoration curves, and is converted to a BI dollar loss estimate based for each financial perspective.



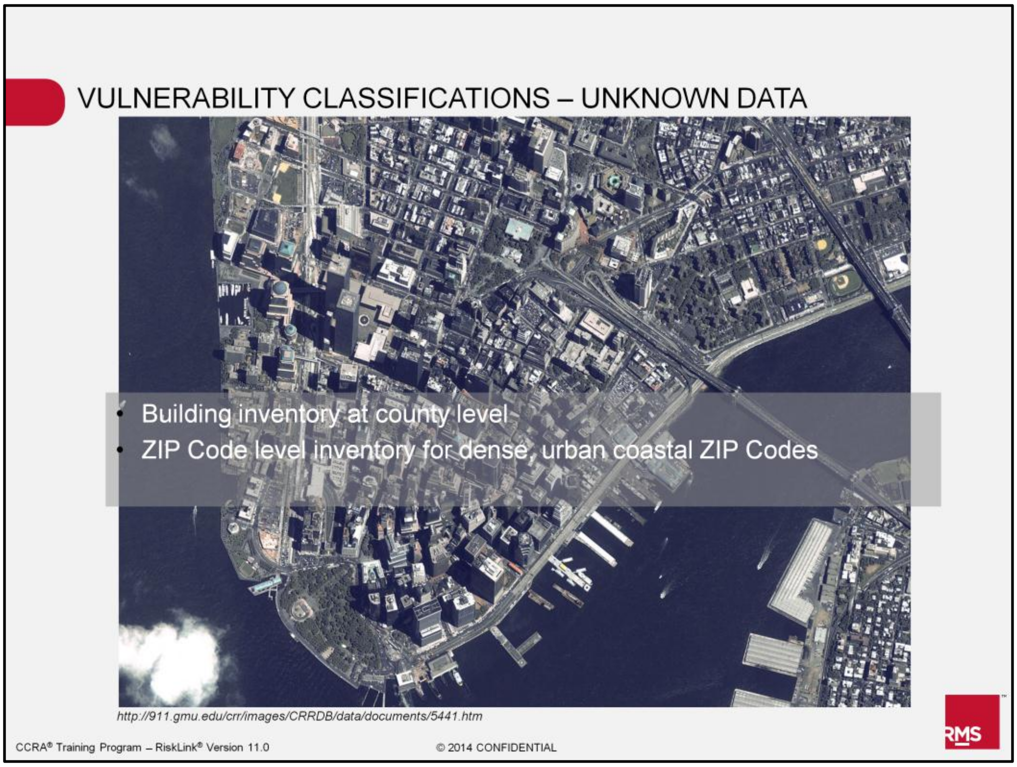
When calculating commercial BI losses, in addition to considering damage to the individual facility, we also consider the impact of non-operational lifelines on the functional restoration time for a location. Restoration times for these lifelines are dependent on wind speeds and have been determined for the lifelines that are listed on this slide, ranging from water and waste water supply to air, sea, and water transportation.



Before going further, it is important to briefly mention the RMS Industrial Facilities Model. The industrial facilities model covers the occupancies listed on this slide, ranging from heavy industrial and light industrial facilities to energy-producing facilities and a handful of other industrial facilities, such as ports and harbors, communications and telecommunication, and data processing. This is not a complete list, but it gives you an idea of the type of industrial risks classified in the industrial facilities model

Up to this point all of our discussion has dealt with individual buildings of an individual class. But each one of these occupancies consists of a complex set of numerous components, often consisting of machinery and equipment.

For the industrial facilities model for each of the occupancies, we have assessed the vulnerability for the various components and created aggregated structure and contents curves weighted by the relative values of the various components. This creates a quick way to refine the vulnerability assessment of these complex occupancies.



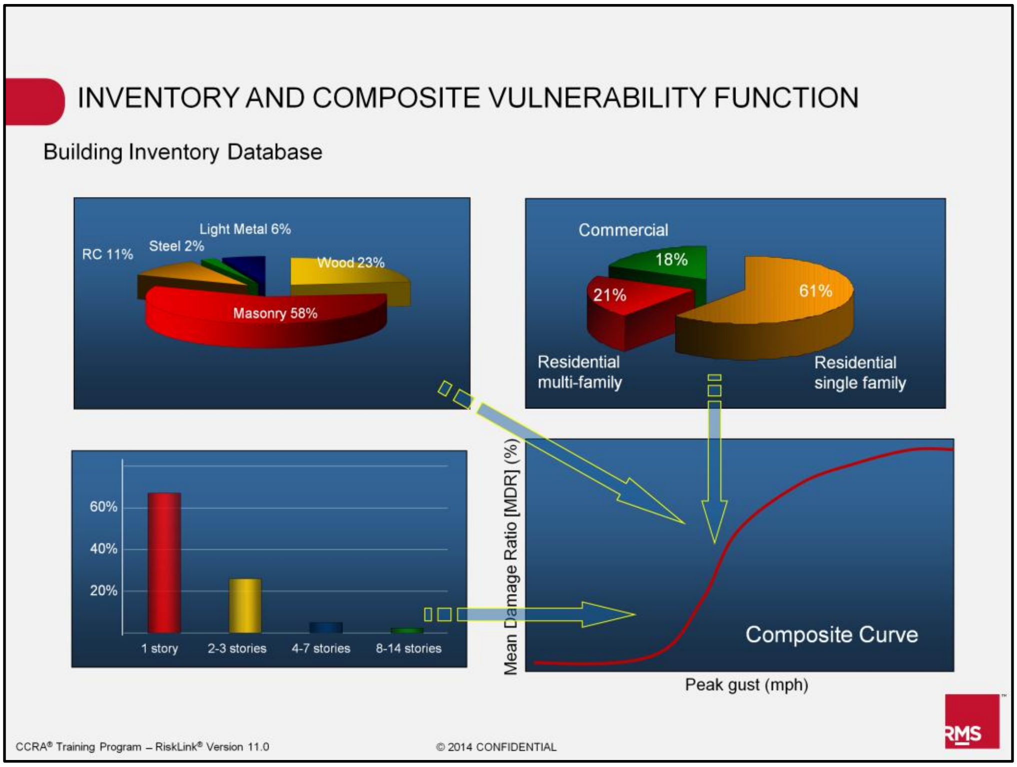
So far we have discussed the quantification of vulnerability when at least the primary characteristics of the building are known. But what happens if occupancy, or as is more often the case, building material or height is not known? In those cases we need to make use of building inventory information to infer average building conditions given the information that is provided.

For instance, if building class is unknown, we need to infer the likely building classes given occupancy, building height, and location. Similarly, if building height is unknown, we can infer the likely distribution of building height given occupancy and location of a building, for instance, downtown Manhattan or in a rural area.

UNKNOWN PRIMARY BUILDING CHARACTERISTICS

- Unknown building characteristics:
  - Unknown construction class
  - Unknown occupancy
  - Unknown height
  - Unknown year built
  - Mix of all possible unknown conditions
- Inventory distributions:
  - U.S. (excluding Hawaii) – hurricane at ZIP Code level
  - Japan – typhoon at prefecture level
  - Caribbean – island group
  - Hong Kong – three regions
- Composite damage functions

Building inventory distributions are created to handle cases when any of the primary characteristic information is not known, or any mix of the characteristics is not known. The level of resolution of the building inventory data varies by model and region. Refer to the RMS model methodology documents on www.rms.com for each peril region for more information. In each case, composite vulnerability functions are developed which represent the mix of buildings expected given the input information that is provided.



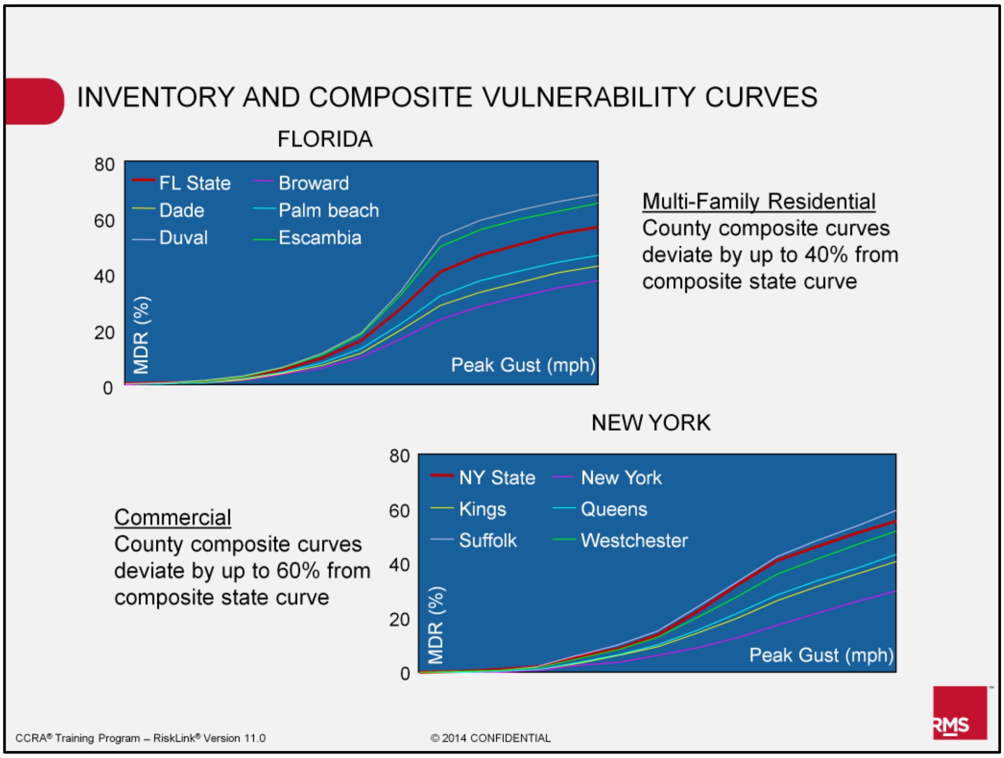
To say this in a different way, a weighted average of construction, occupancy, height, and age is taken to develop a composite vulnerability curve based on the location of the structure.

For example, if nothing is known except that the building is in Melbourne, Florida, the model might assume a mix of building material that might be something like 23% wood, 58% masonry, 11% reinforced concrete, 2% steel, and 6% light metal.

In the same manner, an occupancy distribution may be something like 21% residential multi-family, 18% commercial, and 61% residential single family if the occupancy were not known.

And, finally, if the heights were not known, the inventory distribution will tell us that the distribution of building heights would be something like 67% one to two-story, 5% four to seven-story, and 2% greater than seven stories.

In any case, the building inventory mix will be used to create a percentage-weighted composite curve representing an average condition if any one of these pieces of information is not known.



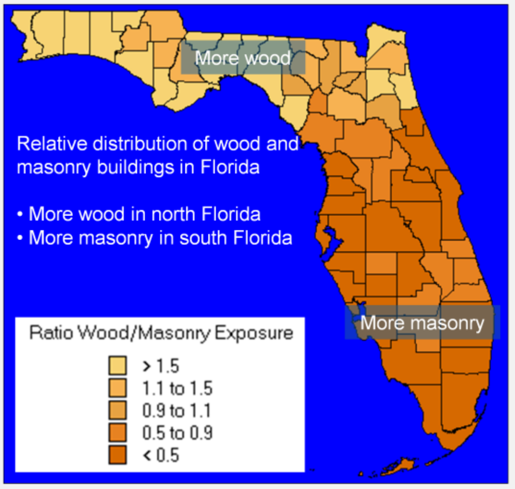
Shown on this slide are examples of variation in building inventory composite vulnerability curves within a state for two different lines of business.

In the upper chart on this slide are composite vulnerability curves for multi-family exposures in five different counties in Florida, as well as the Florida statewide average. As can be seen, the distribution of building classes in the different counties results in appreciably different composite vulnerability curves. So in areas where there is a higher predominance of high-rise multi-family housing, you are going to get a lower composite curve than in areas where most multi-family housing is one or two stories.

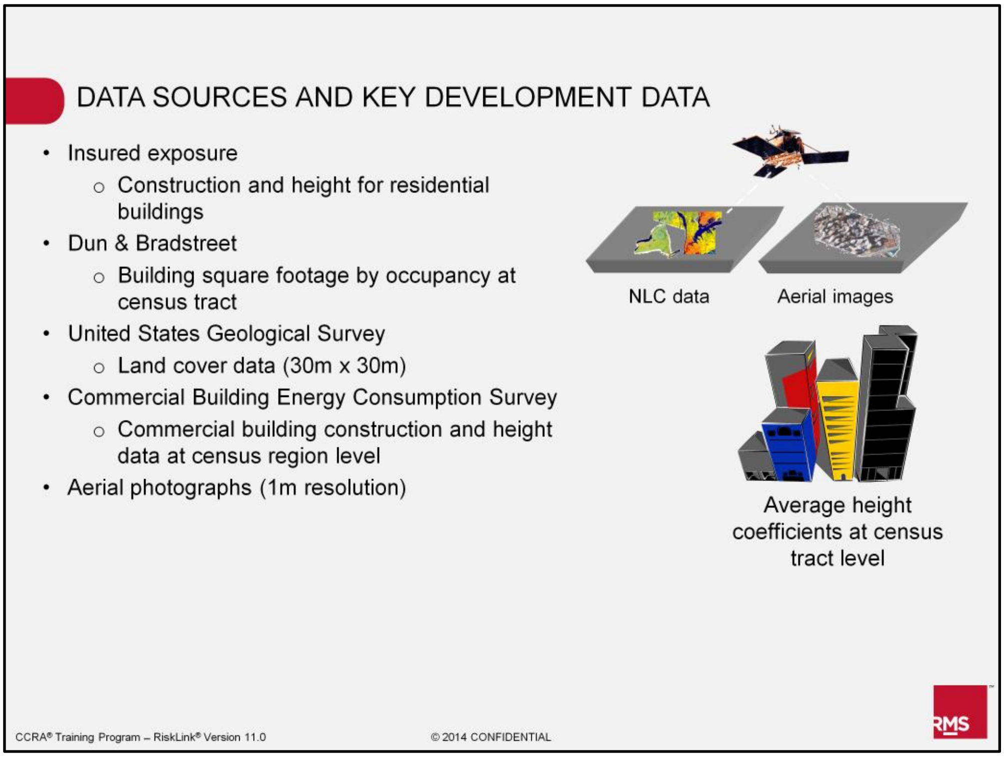
In a similar manner, at the bottom of the slide we show an example for New York. As can be expected in a place like New York City, the composite vulnerability curve reflecting the numerous high-rise buildings there are much lower than what you would expect on a statewide average and also what you would expect compared to other counties within the state of New York.

BUILDING INVENTORY – FLORIDA EXAMPLE

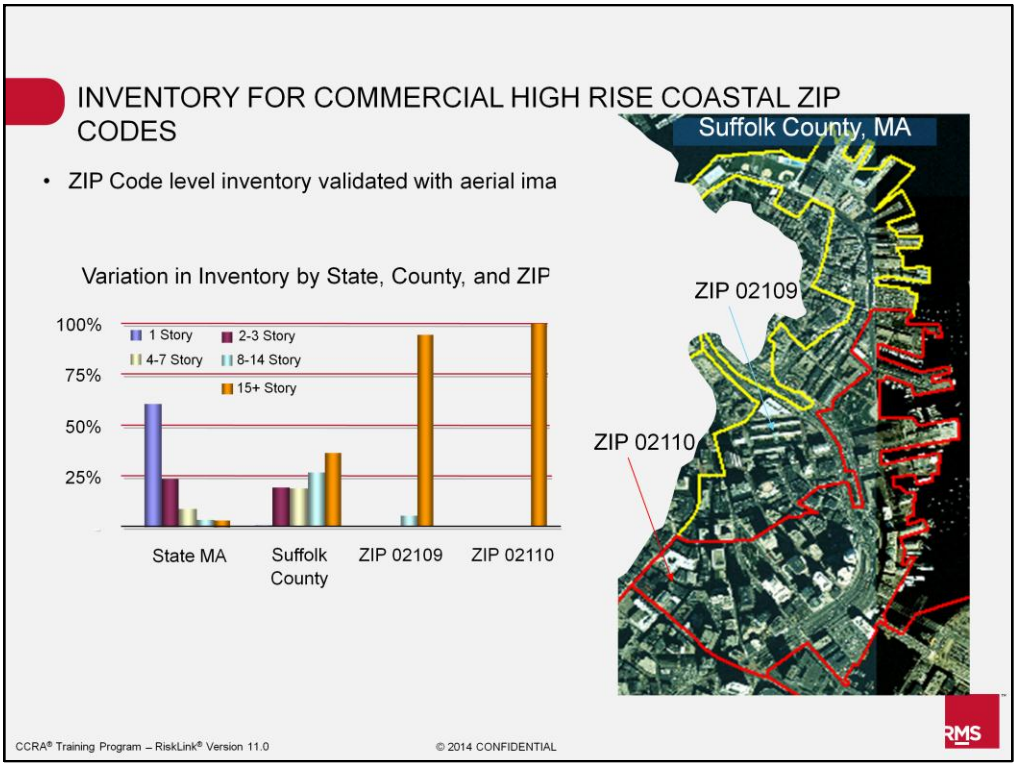
- Building inventory is compiled at the ZIP Code level.
- For unknown construction, relative vulnerability between north and south FL is represented.
- Better modeling of the regional spread in losses



As an additional example, for Florida the building inventory is at a ZIP Code level of resolution. This regional break-out of inventory resolution is able to account for the fact that there is more masonry construction in southern Florida and more wood construction in northern Florida and therefore is better able to account for regional differences in vulnerability. So if you had a portfolio in Florida but did not know the construction type for single-family residential, the inventory data would accurately reflect what percentage is masonry versus wood.



The development of the inventory requires data that must be compiled from many sources. Some of these data sources include insured exposure data and data from organizations such as Dun & Bradstreet to provide square footage by occupancy at a census tract level. That data is used to estimate the building height distributions. Land-cover data from the USGS and other studies, such as commercial building energy consumption surveys, is also used. Thus many sources of data are utilized in order to try to estimate what the building height and building class distribution is and how that varies throughout hurricane states. Finally, aerial photographs are also used in this process to validate our assumptions.

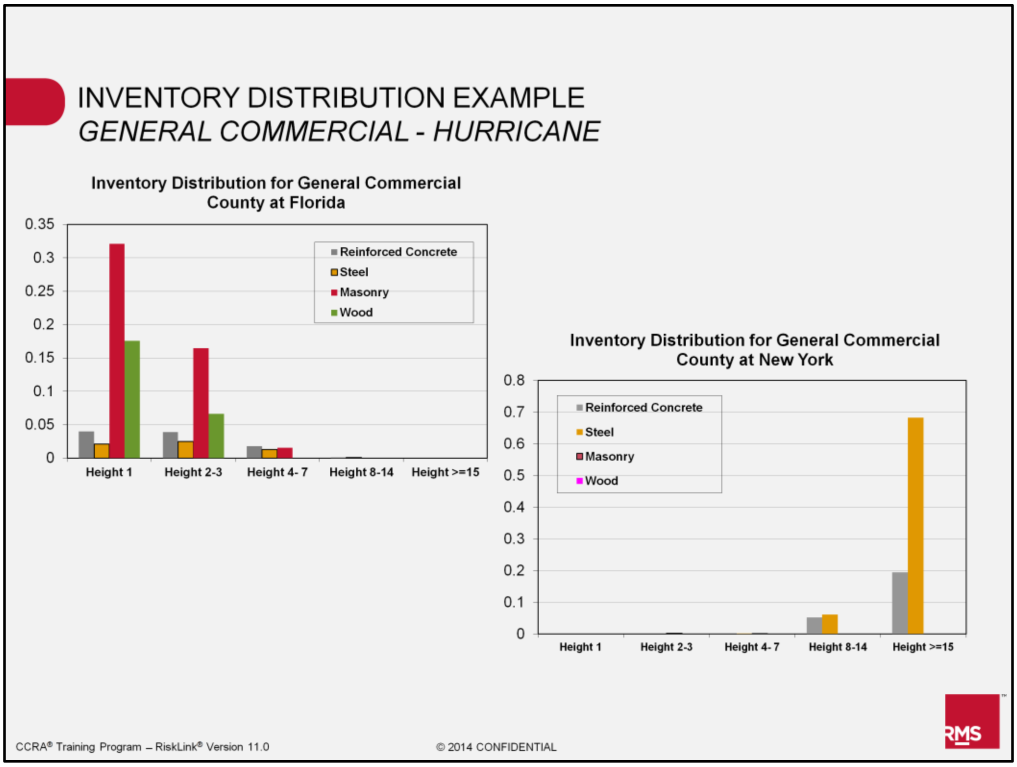


Aerial photography is particularly useful in areas with a high density of high-rise buildings. This slide illustrates the variability in default inventory at three levels of resolution in Massachusetts.

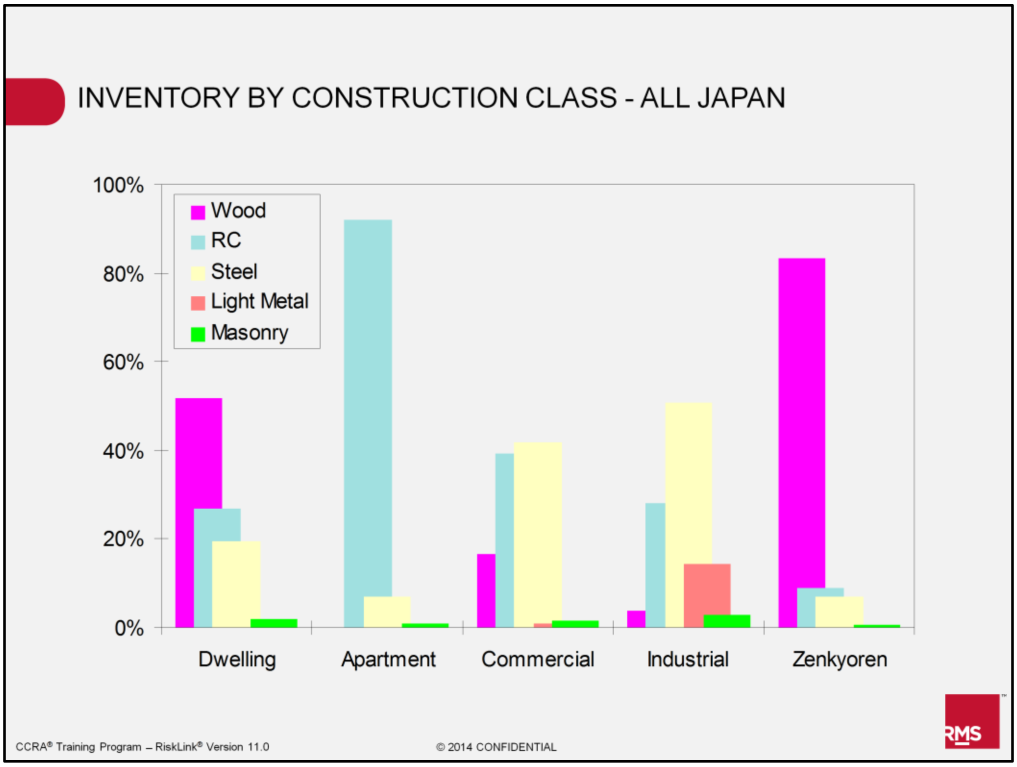
If we start out at the state level, we can see that greater than 50 percent of the buildings on a state level are one story. However, if we go to Suffolk County, we can see that buildings with more than 15 stories are the predominant building height exposure weighted within the county. And even more drastically, if you go to particular ZIP Codes, in this case ZIP Code 02109 or 02110, we can see that the buildings in those ZIP Codes are almost all greater than 15 stories.

So if you were analyzing exposure in one of these ZIP Codes but do not know the building height, the inventory data in RiskLink can reflect the fact that a majority of exposure in that ZIP Code is high-rise and model the vulnerability appropriately.

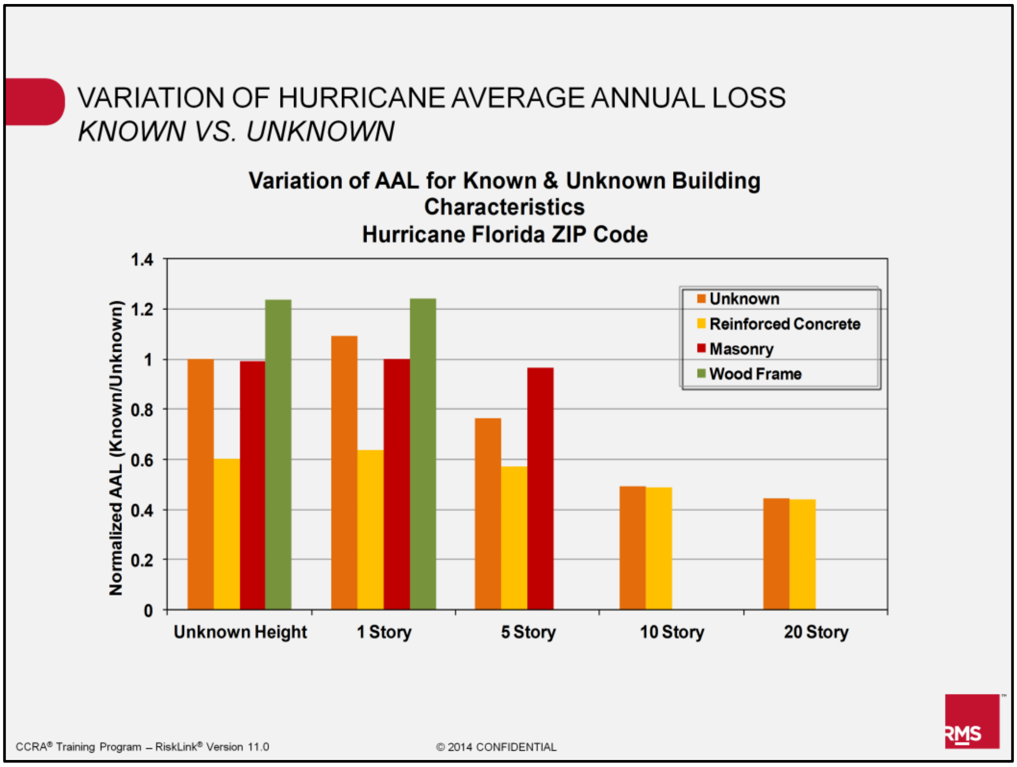
It is worth noting that the Sanborn building-level geocoding in urban centers also provides building height information.



This slide provides additional examples of the range of building mixes that are present in the inventory distribution. For a typical county in Florida, most of the inventory will consist of low-rise wood and masonry construction whereas in New York, most of the exposure will be high-rise and consist of concrete and steel construction. If the statewide average building distribution was used in New York City, losses would be overestimated by quite a bit, as the inventory would incorrectly include too much low-rise construction.

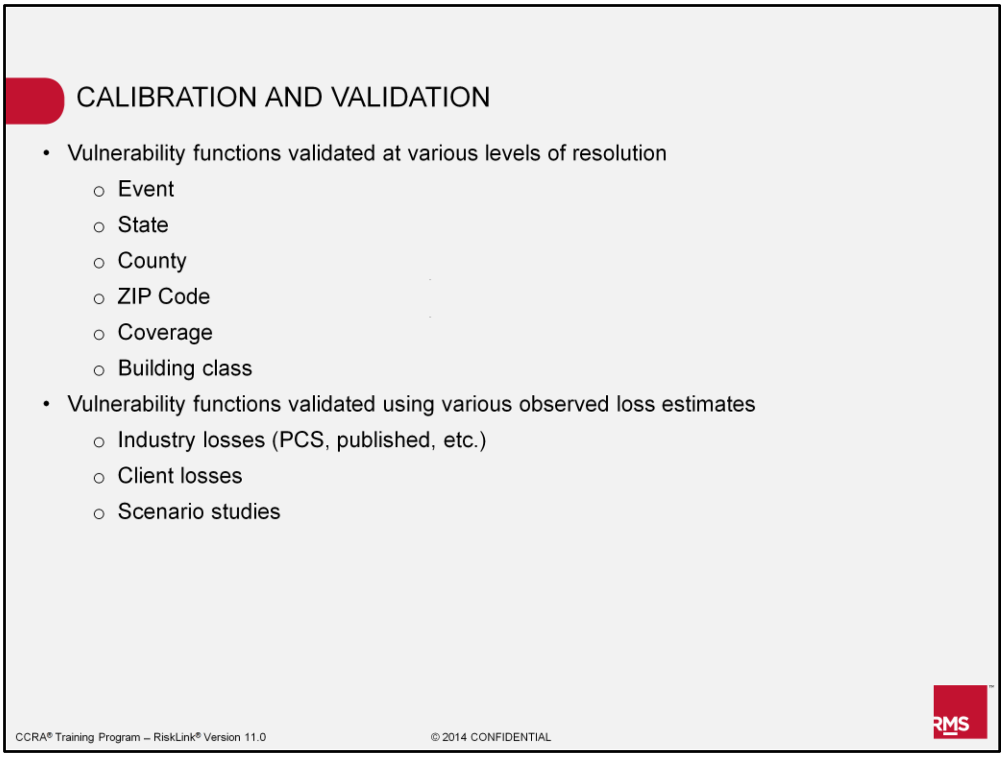


This is an example of industry distributions in another country, the bar chart shows that Japan Zenkyoren line of business exposures are comprised mostly of wood, whereas commercial and industrial inventories consist mostly of concrete and steel construction. So these inventory principles apply to all countries where we model tropical cyclones.



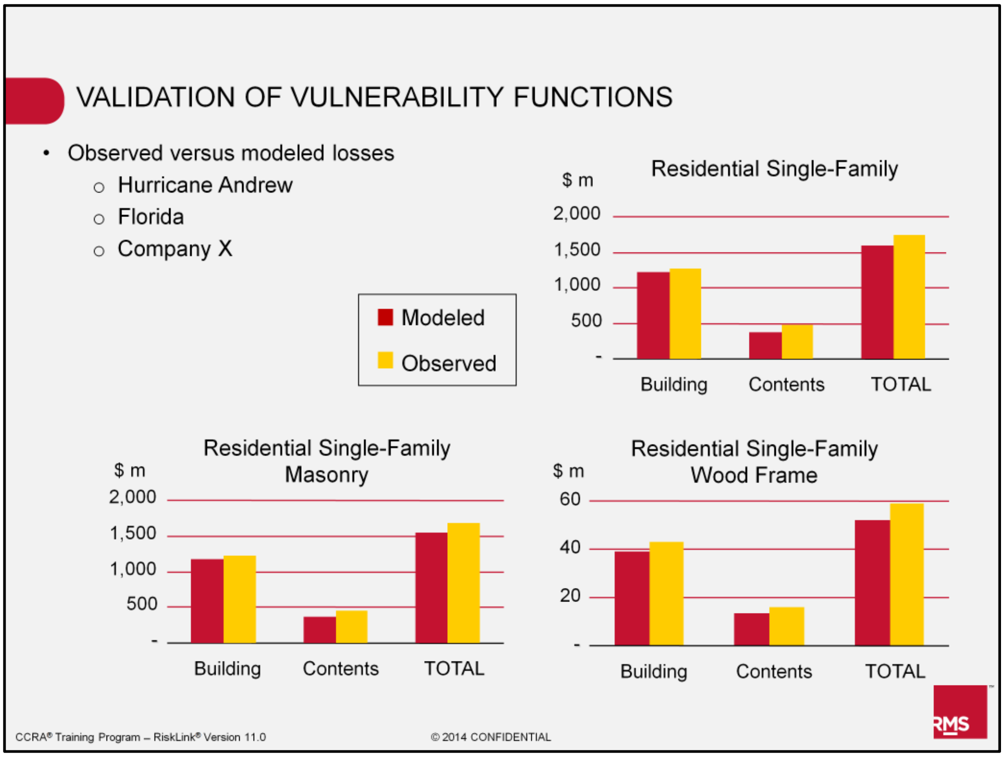
Finally, here is an example of the relativity in risk between unknown and known building height designation for a ZIP Code in Florida. The first set of columns represent unknown height for three different types of construction and unknown construction. If the loss for the unknown height is set to one story, the relative variation in loss for a wood-frame case would be 1.2 and for concrete 0.6. For the one story case, the relativities are similar. However, going to the five story case, since wood construction is not built to five stories, the inventory mix must consist of concrete, masonry, or steel, and the relative difference between the unknown and known cases is not that large.

Of note in these illustrations is the fact that the unknown case represents a mix of building classes and, therefore, results for an unknown case will fall somewhere between the extremes of the known cases.

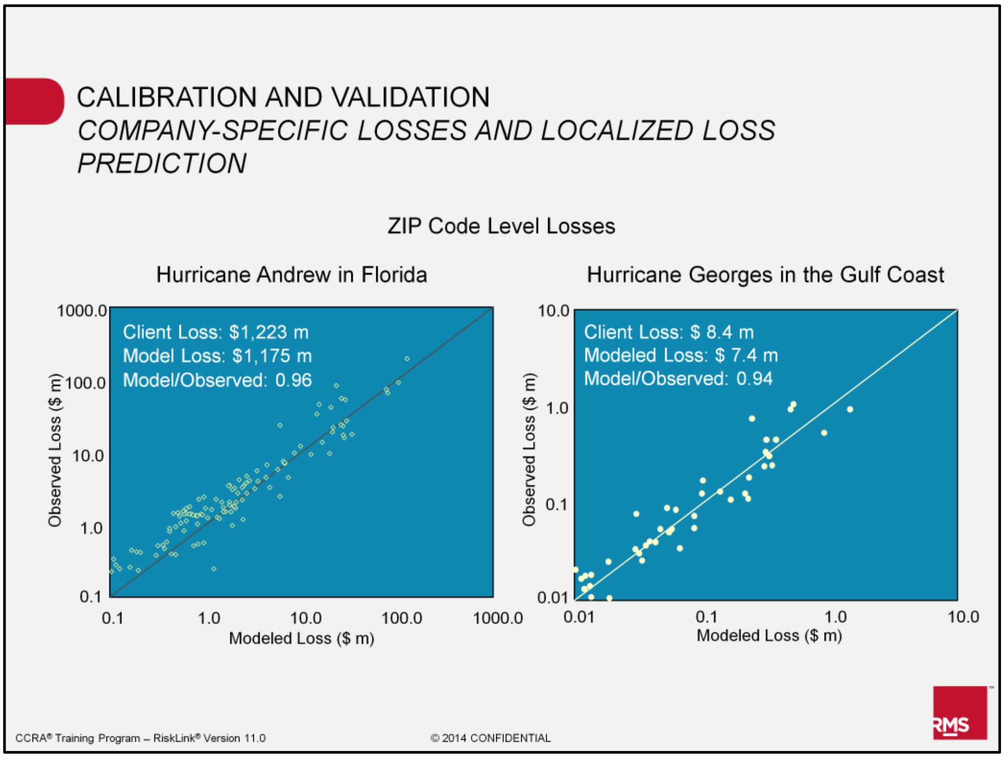


A critical part of vulnerability function development is model calibration and validation. This ensures that the vulnerability functions are consistent with actual observations to the extent that they are available.

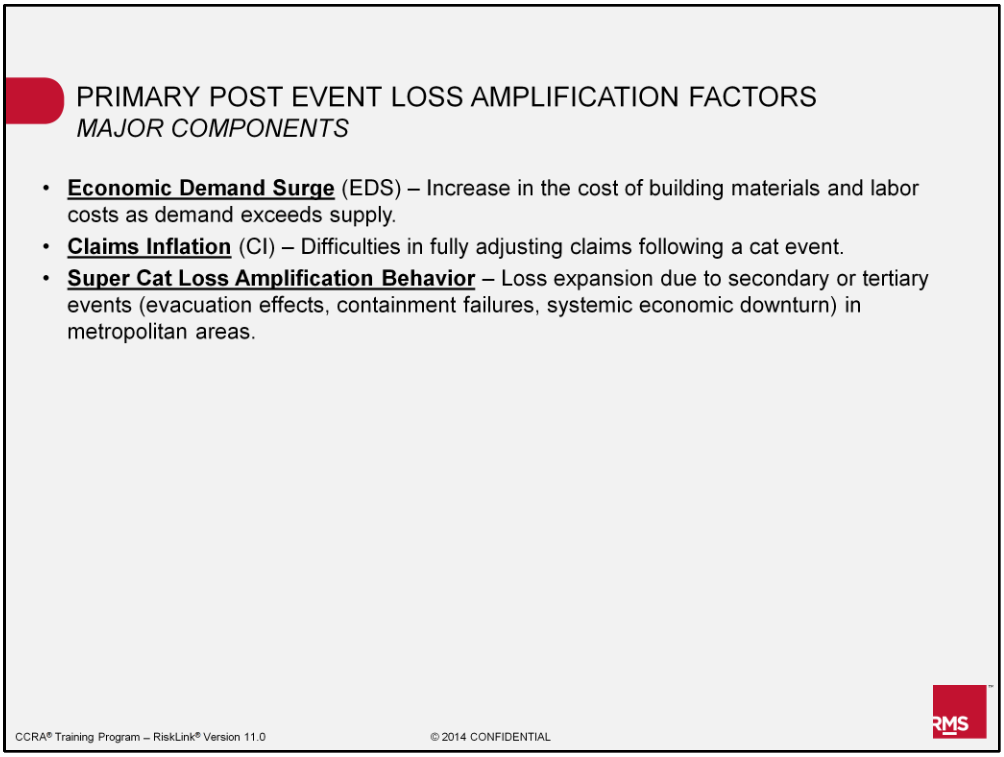
The vulnerability functions need to be validated at various levels of geographic resolution (e.g., state, county, and ZIP Code). They also need to be validated by coverage and building class. Industry data is often used to validate the vulnerability curves; however, loss validation at a high level of detail, essentially building by building, is preferred.



This slide illustrates the type of comparisons that will be made on an industry level, in this case comparing modeled and observed losses for building and contents exposure for wood frame and masonry construction. This kind of comparison can be made for multiple storms and multiple client portfolios. It is not expected that each comparison will result in a model to actual loss ratio of 1.0. However, these types of comparisons can highlight any potential consistent biases.



In addition to looking at losses on an aggregate basis, it is important to confirm that the geographic distribution of losses is correctly estimated. These charts show comparisons of modeled versus actual losses across ZIP Codes for individual storms. Each point in this graph is an individual ZIP Code. It is only through calibrations such as these that we can become confident in the overall vulnerability model.

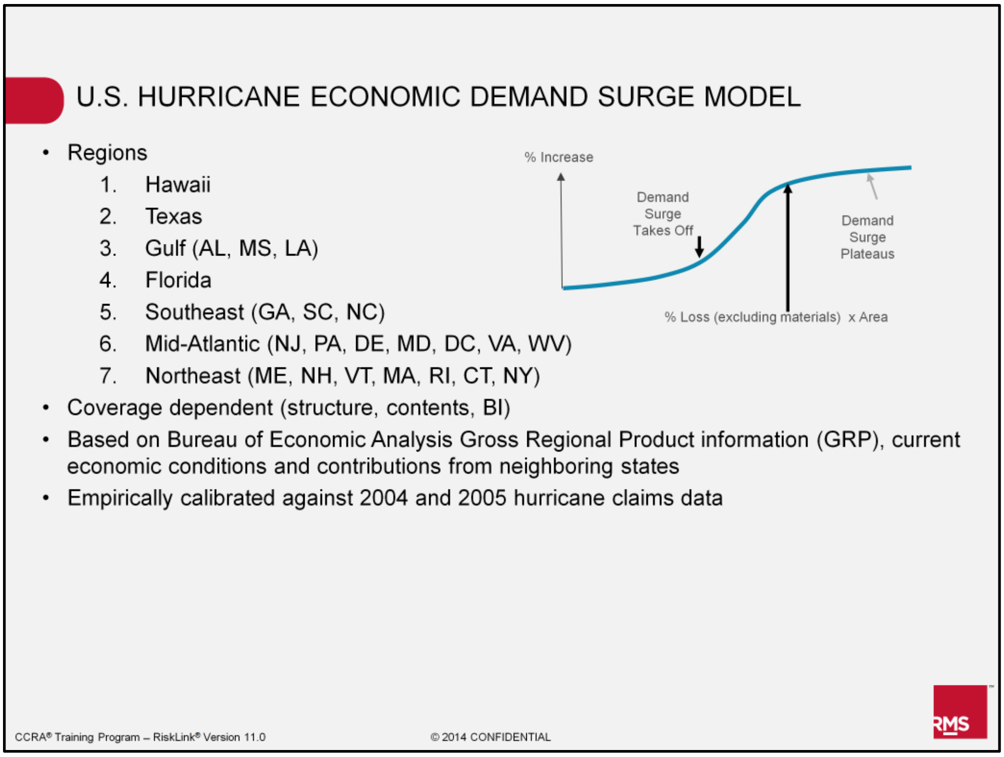


The final topic to be covered in this unit is the recent research in loss amplification impacts on claims losses and approaches to including this factor in modeled losses.

Research into Primary Post-Event Loss Amplification (PLA) has resulted in an expanded modeling component methodology that quantifies three major components that escalate loss following major catastrophic events:

1. **Economic demand surge (EDS):** Increase in the costs of building materials and labor costs as demand exceeds supply. This factor has the biggest overall impact.
2. **Claims inflation (CI):** Cost inflation due to the difficulties in fully adjusting claims following a catastrophic event. For example, shortcuts (such as setting a threshold loss amount under which claims are simply paid with little to no investigation) are practices historically taken by insurers who are overloaded with claims following a catastrophic event. Intuitively, the impact of this factor varies with the estimated number of claims occurring for an event. Overall, CI has a minor impact compared to the other two PLA components.
3. **Super Cat scenarios:** Coverage and loss expansion due to a complex collection of factors such as containment failures, evacuation impact, and systemic economic downturns in selected urban areas. This factor has an impact for high return period events striking earthquake and hurricane exposed metropolitan areas.

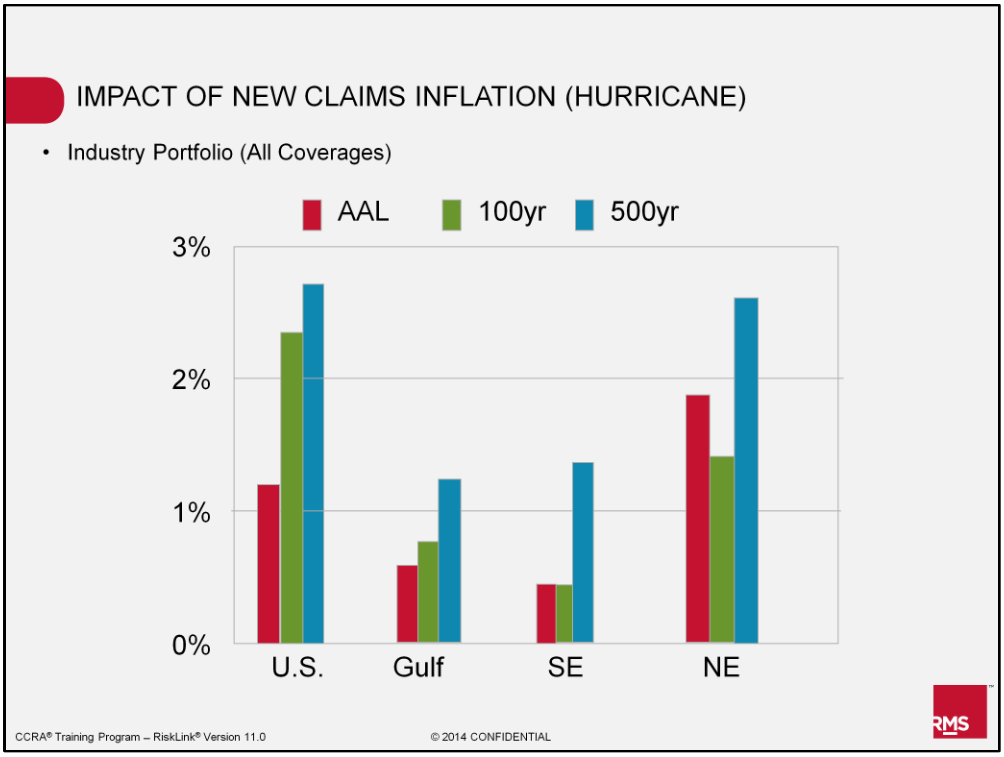
There are also two other secondary loss amplification components worth mentioning. **Repair Cost Delay Inflation:** This is the time dependent damage escalation caused by delays in making repairs. **Coverage Expansion:** This refers to the expansion of insurance terms and coverages, often as a result of political pressure. Both of these components are not well documented from claims records, and are thus not currently modeled in RMS applications.



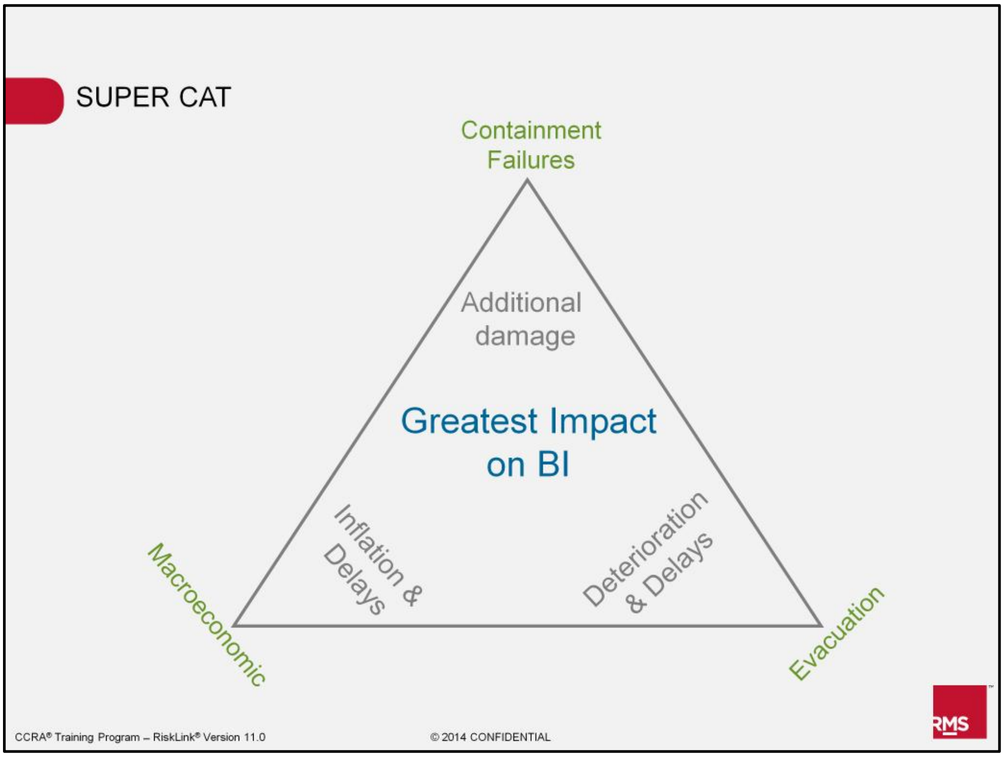
In this slide, an example of an economic demand surge (EDS) function is displayed (the first component of the PLA model). Note that the relationship follows an S-curve over the course of the entire EDS function with inflection points at 2%, 50%, and 97% of the maximum EDS. This is the observed behavior of actual EDS following events as tracked by RMS. The threshold or trigger point for the initiation of demand surge is determined by the capacity in the repair sector by region as estimated by RMS. For the U.S. Hurricane model, the trigger points to initiate EDS are the same for the entire U.S.; however, the slope of the curves vary by region due to regional differences in the capacity of the repair sector to address material and labor shortages as estimated by RMS.

Hurricane economic demand surge was quantified for each of the U.S. state regions listed on this slide for each coverage (structure, contents, and business interruption). The EDS component calculation consists of dividing the ground-up modeled loss for a region using the RMS Industry Exposure Database (IED) by the gross regional product (GRP) for the region and peril in question. Following the 2004 and 2005 hurricane seasons, a robust sample of both residential and commercial claims was collected to quantify the EDS experienced by the industry. Collectively this data was used to empirically calibrate the EDS component of the PLA model.

Beginning with RiskLink 11, the gross regional products were updated with latest available data. Industry losses for each stochastic event was based on 2011 RMS industry exposures. RMS also considered the state of the economy and level of unemployment. Given everything is the same, the version 11 PLA model will provide less loss amplification impacts.



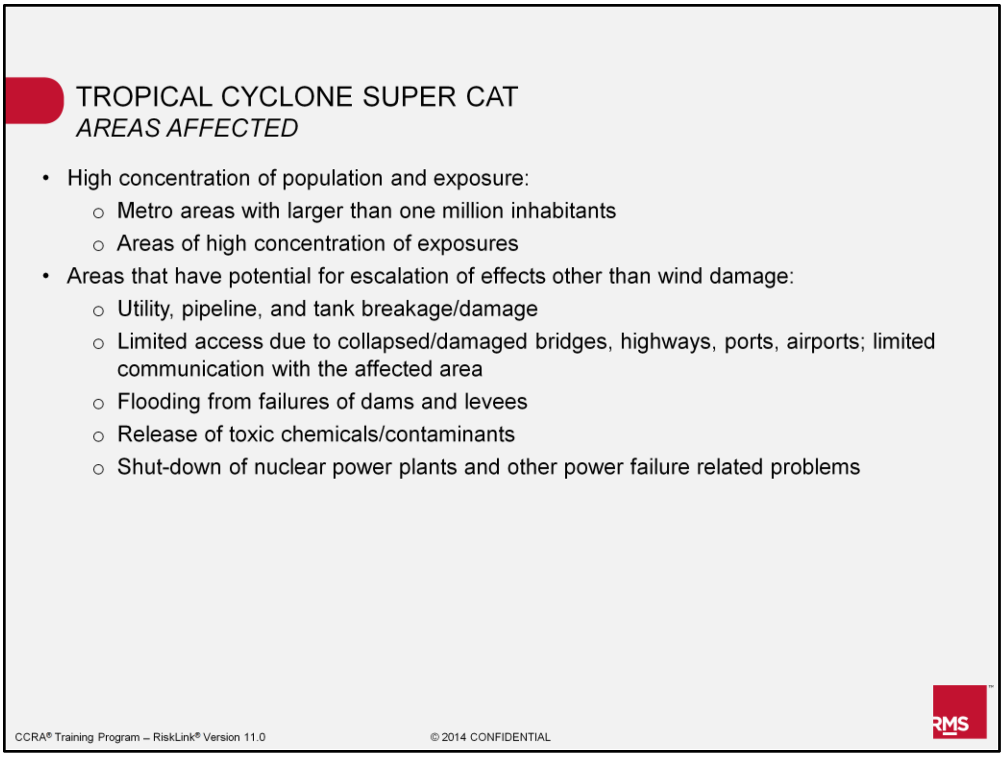
This figure shows the impact of claims inflation (the second component of PLA) for U.S. hurricane analyses performed on the RMS Industry Exposure Database. Note that while the maximum impact for any U.S. hurricane peril is capped at 6%, the impact is never higher than 3% for the U.S. regions shown here. As such, the impact of claims inflation on overall loss amplification is very small.



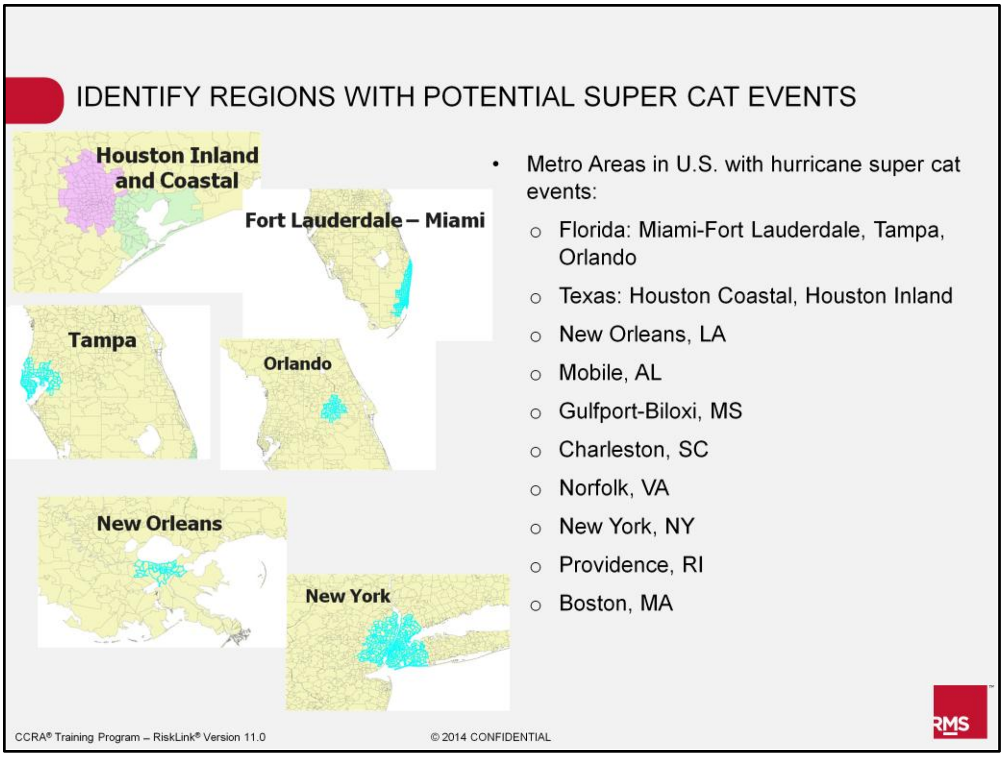
We now address the third component of PLA – hurricane super catastrophes (Super Cat). These are extremely high severity events characterized by:

- Containment failures (e.g., levee breaks)
- Widespread long term evacuation
- Systemic macroeconomic impacts (e.g., hotels/stores staying closed because there are no customers and absence of labor force to make repairs)

These non-modeled (or secondary consequence) event losses are a major proportion of loss in Super Cats. At the extreme, the non-modeled loss can become larger than the original event. The largest escalation of loss for Super Cat hurricane events occurs with respect to business interruption coverage.



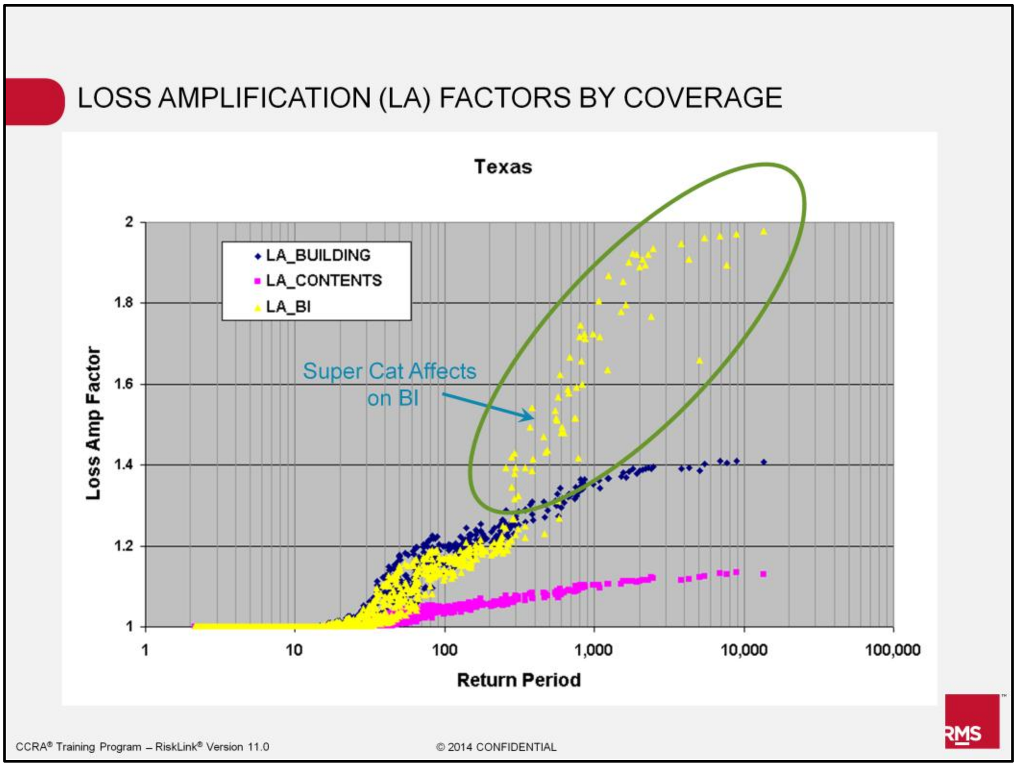
The selected urban areas where hurricane Super Cats will occur are defined to contain more than one million inhabitants with high concentrations of insured exposure. These metro areas will be exposed to significant loss escalation due to both the modeled peril (wind) and non-modeled hurricane related losses (inland flooding, theft, looting, arson, contamination, etc.). The Super Cat impact for the metropolitan areas incorporated into the model was determined by using RMS-modeled results and a case-by-case analysis of the impact of the key elements of Super Cat behavior. For the hurricane peril, this includes the susceptibility of the urban area infrastructure (transportation, communications, utilities, etc.) to damage that could lead to Super Cat effects.



Shown on this slide are some examples of metro areas that could be impacted by Super Cat events. Super Cat events are identified as those events whose track passes through or close to the regions encompassing the metro areas shown on this slide. As an example, only a hurricane that passes near or through the Houston urban center and/or coastal areas near Houston will be considered a potential Super Cat event, depending on the incurred losses by the affected exposures in these areas.

In addition to the track location, a metric used to identify hurricane Super Cat events in the RMS stochastic event database is the ground up loss ratio = loss/exposure in the areas of large concentration of exposure shown in shaded areas. If this value exceeds a threshold which represents the degree to which an urban area is severely damaged, then it is a potential Super Cat event. For the U.S. Hurricane model there are 852 (2.3% of the total number of stochastic events) unique Super Cat events. Some of these events strike more than one metro area.

Finally, events classified as Super Cat events have a higher degree of location correlation, and can be identified with a correlated component of loss greater than 15% in the dbo_correlation table located in the RMS EVENT INFO database.



To further exemplify the difference between Super Cat and non-Super Cat events, we take a further look at calculated primary loss amplification (PLA) factors for Houston, Texas (the only Super Cat metropolitan area included in the Texas region). Each triangle on this graph represents a separate stochastic event for which there is a modeled ground up average annual loss (AAL) and PLA factor for the RMS U.S. residential industry exposure data (IED). To arrive at these numbers, a windstorm analysis was run for each ZIP Code in the urban area. The Y axis on the graph represents the degree of loss amplification calculated for each event. The plot shows that Super Cat events begin to substantially escalate the PLA impacts on business interruption/alternative living expenses at return periods in excess of 300 years for this region. Thus, the events circled on the graph represent identified Super Cat stochastic events for Houston.

UNIT 3: TROPICAL CYCLONE WIND VULNERABILITY

KEY CONCEPTS

- Building performance is largely dependent on the ability of exterior elements such as roofing, sheathing, and cladding to resist wind pressures.
- Failure of exterior building elements allows wind and rain to enter a structure, resulting in the potential for substantial losses.
- Development of vulnerability functions is based on a combination of empirical claims data and engineering analytical modeling.
- Providing information on building specific secondary modifiers can refine loss estimates and reduce uncertainty.
- When specific building information is not known, default inventory assumption are utilized.

To summarize Unit 3, building performance is largely dependent on the ability of exterior elements, such as roofing, sheathing, and cladding, to resist wind pressures. We have shown that failure of existing building elements allows wind and rain to enter a structure, resulting in the potential of substantial losses. The development of a vulnerability function is based on a combination of empirical claims, data and engineering, and analytical modeling. Providing information on building-specific secondary modifiers can refine loss estimates and reduce the uncertainty in loss estimates. And, finally, when specific building information is not known, inventory assumptions are utilized.

This concludes Unit 3 of the Tropical Cyclone Modeling course.