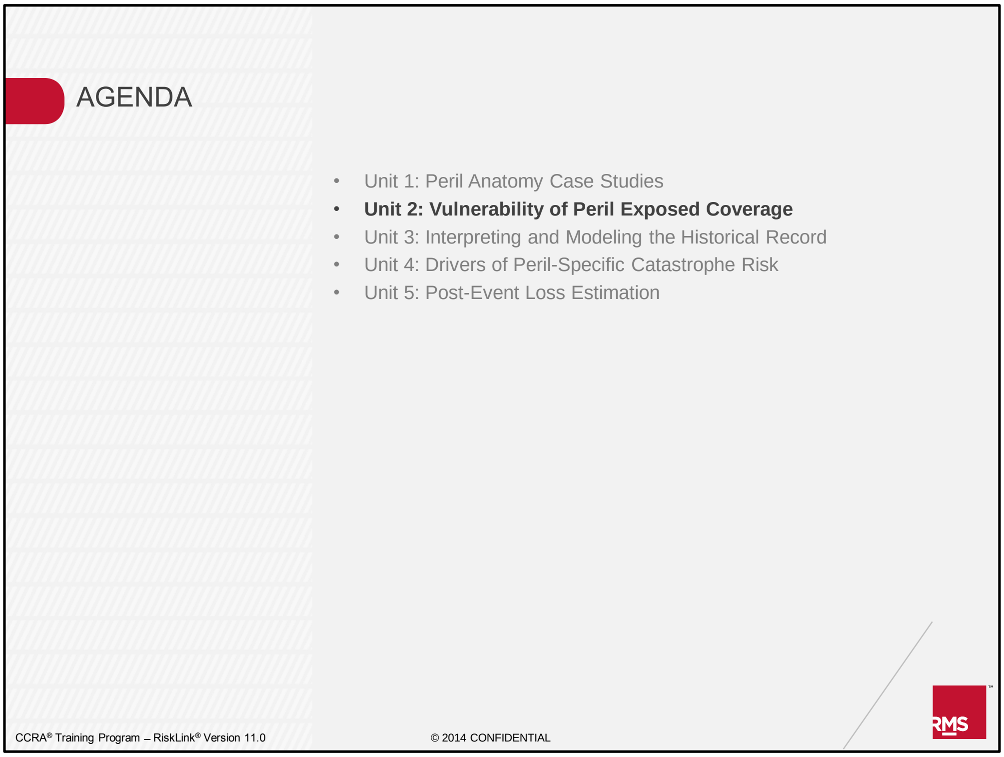
SEVERE CONVECTIVE STORM MODELING

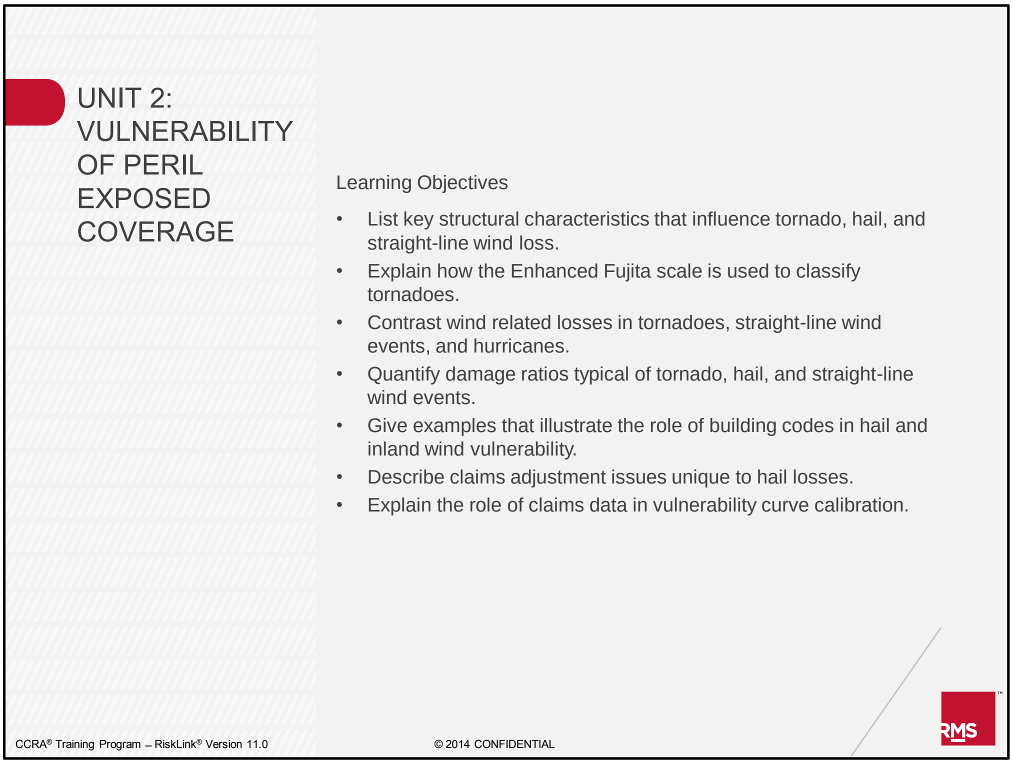
UNIT 2

RMS® CCRA® Training Program

Certified Catastrophe Risk Analyst



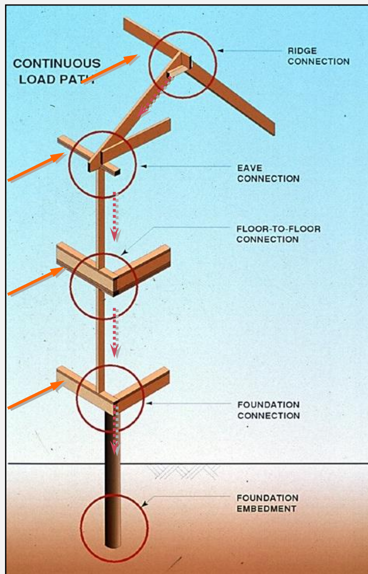
This unit discusses the vulnerability module of the severe convective storm model.



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

WIND EFFECTS ON BUILDING COMPONENTS – THE LOAD PATH

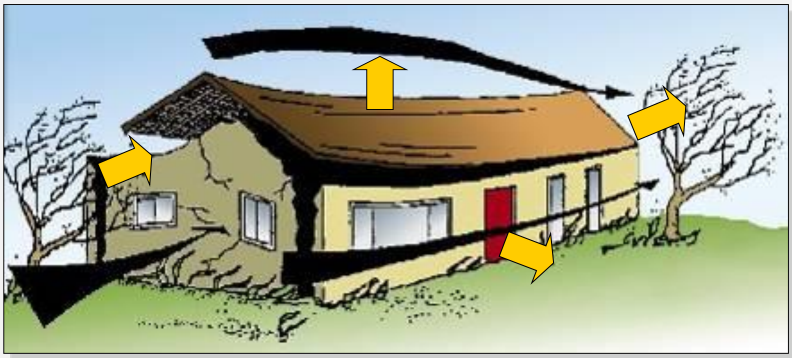
- Load path
  - Loads transferred by building elements and by connections between the elements into the foundation.
- Continuous load path
  - Essential for resisting not only gravity loads but also lateral and uplift loads due to wind.
- Adequate connections between:
  - Roof covering and sheathing
  - Roof sheathing and framing
  - Roof framing and walls
  - Walls, floor, and foundation



Buildings are designed to carry dead loads, or gravity loads, and the weight of the structure and its contents. In addition, they are designed to resist lateral forces. Those lateral forces could be from winds or debris. The forces imposed on the building ultimately get transferred down to the ground through a continuous load path, which is very critical for resisting the forces of the wind. The critical element is the strength of the connections within each of the points in the load path, including the connection from the rafters to the walls, from the walls to the foundation, etc., on down to the ground.

WIND EFFECTS ON BUILDINGS – 101

- Pressure on windward wall
- Suction on leeward wall, side walls, and roof



Source: FEMA

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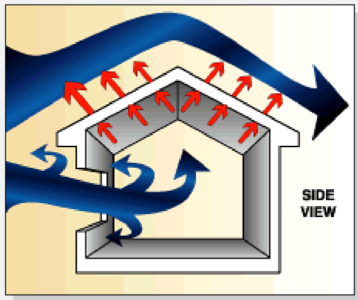
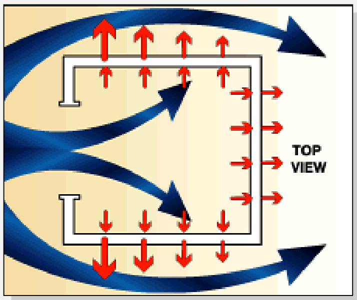
When wind is impacting a building it creates dynamic pressures on the walls and on the roof of the building. The windward wall has an inward force or an inward pressure. The leeward wall, which would be in the background of this image, would have an outward force. And, in general, the roof would have an upward force when there are strong winds, as shown from the foreground to the background of this diagram. As the wind speed increases, these forces also increase to the point where, ultimately, the force being introduced onto the roof and the walls can overcome the resistance of those connections, and the building components could begin to fail.

WIND EFFECTS ON BUILDINGS – 101

- Suction on roof
  - Internal pressure adds to roof uplift

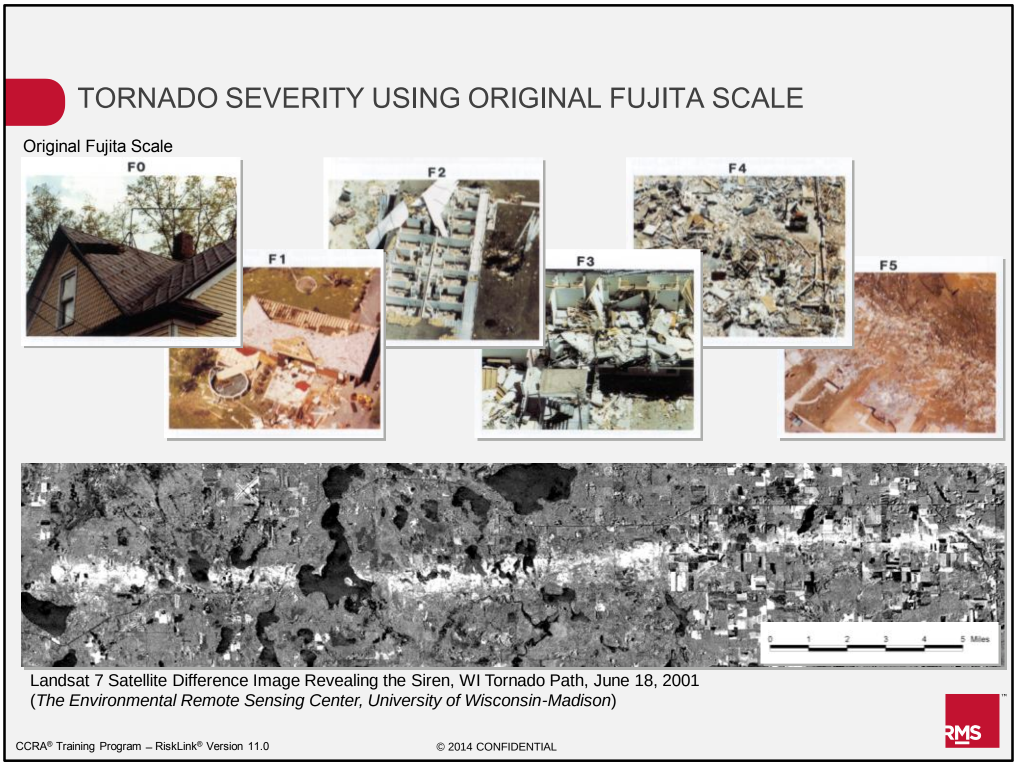


Source: FEMA



- Suction on leeward and side walls
  - Internal pressure adds to wall suctions

One of the critical elements to wind resistance in a building is the structure's opening protection, or how well the building elements are able to resist having a window or a garage door failure. An opening into the home or building would then allow the internal pressures within the building to increase dramatically as winds are brought into the building. The result is a greater force that could cause the roof to fail, and then the walls to fail outward. That is often visualized in a progressive failure mode where the roof fails first and then walls also fail based on that buildup of internal pressure.



With that as background, the wind environments of tornadoes and straight-line winds and their effects on structures will be discussed next. The wind speed of a tornado is something that cannot be directly measured. So the severity of a tornado has to be inferred from the damage it causes either to buildings or vegetation. The approach of inferring damage is very analogous to the MMI scale that is frequently used to estimate or characterize earthquake intensity.

The scale that is used to infer tornado winds is the Fujita Scale, which was established by Dr. Ted Fujita in the early 1970s. It was published in 1971 and later put into routine practice by the National Weather Service over the following several years.

As tornadoes are reported, surveyors review damage, and then they classify that tornado to an F rating of F0 to F5 based on the peak damage that is observed anywhere on its path. That peak damage is then related to a wind speed based on a relationship that was proposed by Dr. Fujita when he published this initial scale. The wind speed range that was published back in the 1970s was an approximation. It was based on Dr. Fujita's intuition and was not very well tested from an engineering point of view.

When you look at these images in the upper part of this slide, one thing that is clear is that for residential property with an F2 damage level where a roof is fully removed, all the interior components of the building are exposed to wind, rain, and other environmental effects. For most cases, that level of damage is very near a total insurance loss. When we look at different buildings that are better constructed or even engineered, an F2 or F3 level of wind speed would produce less severe damage.

This scale was initially designed based on evaluating the damage to a well-built wood frame home and associating that with a wind speed. That wind speed was then used to classify damage. There are efforts under way to make this scale more applicable to a diversity of building types, which we will discuss shortly.

TORNADO SEVERITY ASSESSMENT

- The F-Scale (used routinely since mid-1970s)
  - Reflection of the peak observed damage
  - Does not systematically account for variations in construction quality (peak damage point may be the result of localized poor construction).
- Fujita-Scale Enhancement Project (2007)
  - Identifies additional Damage Indicators (DIs).
  - Correlates damage to wind speed using Degrees of Damage (DOD) for each DI.
  - Preserves the historical database.
  - Based on input from a committee of experts from engineering and meteorology community.

There are some important considerations about this scale that catastrophe modelers should take into account when developing a model. It is important to understand these when asking questions or inquiring about how a model is developed.

The Fujita Scale is inherently subjective, so there is a potential for bias and error when it is applied to rate a tornado. To date, the scale has not been systematically used to account for the variation in construction practices. The scale is applied by a meteorologist going to a site using the guidelines established by Dr. Fujita in some of his pioneering work of the 1970s. Dr. Fujita worked to classify damage using the type of damage a common wood frame home would sustain. Then, by visual inspection of the damage that was caused, he would try and associate it with one of these F ratings. When an event occurs, a diverse group of surveyors, many of whom are not engineering professionals, may be involved in classifying the damage. Many of these surveyors come from a meteorological background rather than engineering; therefore, it is not necessarily applied in a consistent manner.

In addition, the Fujita Scale is not based specifically on an objective and consistent link to wind speed. The figures you often see associated with the Fujita Scale were established using Dr. Fujita’s own intuition at the time, but subsequent studies have indicated that F5 levels of damage to a well-built wood frame home can be produced by lower wind speeds.

The process that is taken to develop a vulnerability model involves correlating tornado severity with a wind speed using the best information available from the engineering community, which today is increasingly better than it was in the 1970s when the Fujita Scale was originally produced.

These wind speeds are then associated with damage ratios based on engineering principles. This is similar to how a hurricane vulnerability function is developed. A damage ratio for a 150 mile per hour peak gust can be established knowing what the design loads are for a building at that wind load. Ultimately the damage ratio can be validated with claims that were actually incurred from an event, where possible.

Engineering principles are also used to further establish the relativity in damage between different construction and occupancy types.

The Enhanced Fujita Scale was officially adopted by the U.S. National Weather Service in February 2007. It was developed by researchers at the Wind Science and Engineering Research Center at Texas Tech University with the goal of modifying the original Fujita damage scale to improve the estimation of wind speeds and tornado intensity classification from damage observations. By design, the EF scale is fully compatible with the original Fujita scale to preserve the relevance of historical tornado record. This means that the general damage level for each of the F intensity ratings is on average equivalent to the corresponding EF intensity. However, one of the main conclusions of this study is that the wind speeds necessary to damage or destroy a structure were being overestimated by the original Fujita scale. More specifically, the EF wind speed ranges are about 30% lower than for the corresponding F scale ranges for certain building types and intensities.

COMPARISON OF FUJITA TO ENHANCED FUJITA SCALE

Fujita Scale (F)	Wind Speed	Enhanced-Fujita Scale (EF)	Wind Speed Ranges
F0	45-78	EF0	65-85
F1	79-117	EF1	86-110
F2	118-161	EF2	111-135
F3	162-209	EF3	136-165
F4	210-261	EF4	166-200
F5	262-317	EF5	>200

Note: Wind speeds in miles per hour

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The EF-Scale is more comprehensive than the F-scale with 28 damage indicators (DIs). It accounts for structural diversity in strength within DIs and its effects on assigning wind speeds to degrees of damage (DODs). Wind speeds are determined from damage using expert elicitation methods. There is continuity from the legacy to the new scale. And the EF-Scale is expandable, meaning new DIs can be added and combined, and estimated wind speeds assigned to the DODs can be modified.

EXAMPLES OF EF DAMAGE INDICATORS (DIS)

- There are 28 damage indicators defined by the EF scale.
- The DIs represent a wide variety of structures.

Example Damage Indicators
One- or Two-Family Residences
Manufactured Home – Single Wide
Apartments, Condos, Townhouses (3 stories or less)
Masonry Apartment or Motel Building
Small Retail Building
Low-Rise Building (1-4 stories)
Mid-Rise Building (5-20 stories)
High-Rise Building (more than 20 stories)
Metal Building System
Warehouse Building

Residential

Commercial, Industrial

There are 28 damage indicators defined by the EF scale. An example of those damage indicators is shown on this slide.

EXAMPLE OF DEGREE OF DAMAGE INDICES FOR ONE- OR TWO-FAMILY RESIDENCES WITH WIND SPEEDS

	Degree of Damage Description	Expected Wind Speed (mph)	Lower Bound	Upper Bound
1	Threshold of visible damage	63	53	80
2	Loss of roof covering material (<20%), gutters, and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed except small interior rooms	152	127	178
9	All walls collapsed	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	162	220

Each damage indicator has a set of degree of damage indices (DODs), which links damage to possible wind speed ranges. Including both the lower and upper bounds around the expected wind speed shows that there is variability in the performance within a class of structure.

The upper bound indicates that the design exceeds codes for typical U.S. homes, with a better than average load path. The lower bound indicates that the design fails to meet U.S. building codes, and has poor maintenance and/or poor load path. The expected wind speed indicates the design exhibits typical construction.

EXAMPLE OF DEGREE OF DAMAGE INDICES FOR ONE- OR TWO-FAMILY RESIDENCES WITH EF RATING

	Degree of Damage Description	Expected EF Intensity	Lower Bound	Upper Bound
1	Threshold of visible damage	< EF0	< EF0	EF0
2	Loss of roof covering material (<20%), gutters, and/or awning; loss of vinyl or metal siding	EF0	< EF0	EF1
3	Broken glass in doors and windows	EF1	EF0	EF2
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch or carport	EF1	EF0	EF2
5	Entire house shifts off foundation	EF2	EF1	EF3
6	Large sections of roof structure removed; most walls remain standing	EF2	EF1	EF3
7	Exterior walls collapsed	EF2	EF2	EF3
8	Most walls collapsed except small interior rooms	EF3	EF2	EF4
9	All walls collapsed	EF4	EF4	EF4
10	Destruction of engineered and/or well constructed residence; slab swept clean	EF5	EF4	EF5

This table shows the EF intensities that correspond to the wind speeds from the previous slide. For most degrees of damage, there is a range of possible EF intensities for a given DOD.

PHOTO EXAMPLES OF EF DAMAGE LEVELS

- Examples of damage to single family homes from EF5 Parkersburg, Iowa tornado, May 25, 2008.

Photo credit Tim Marshall

On May 25, 2008, Parkersburg, Iowa experienced an EF5 tornado, which destroyed nearly half of the town. The photos on this slide show examples of the damage to single family homes in the town.

INLAND VS. COASTAL CODE QUALITY AND ENFORCEMENT

- Weaker wind design codes inland, in many tornado-prone areas
- Example: Kansas and Oklahoma 1999 Tornadoes
  - Residential design in these areas based on 1995 Council of American Building Officials (CABO) code
  - CABO code did not incorporate wind speed design parameters used by 1997 Uniform Building Code and 1996 National Building Code

One other thing to note is that there is significant variation in the level of building codes that are in force in inland regions versus coastal regions. The quality of construction, whether it is a strong or weak residential home, can vary significantly.

There are significantly weaker design standards in the inland regions where there is a peak frequency of tornadoes and straight-line winds relative to hurricane states. One of the key examples that underscored this was the May 3, 1999, Oklahoma City tornadoes that we highlighted in Unit 1. This event is an illustrative example of how some of the codes are less rigorous in these areas and how that ultimately relates to the type of wind risk that would be present in those areas.

The code that was in place at the time was not very strict. What was even more striking was that these lenient codes were also not well enforced. In addition, when buildings were rebuilt after that event, they were not built to the highest standard.

EXAMPLE OF WEAK/BELOW CODE CONSTRUCTION IN OKLAHOMA

- “Buildings constructed to these newer codes and standards would have experienced less damage in areas that were affected by the inflow winds of all tornadoes and reduced the damage where weak tornado vortices directly affected buildings.”

FEMA building performance assessment team report, October 1999

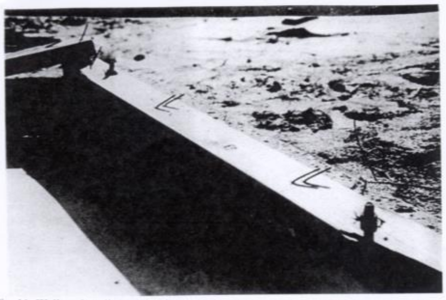


Fig. 11. Wall studs pulled out leaving only the anchor bolted bottom plate. Unfortunately, local building codes still allow straight-nailed connections between the wall plates and studs.

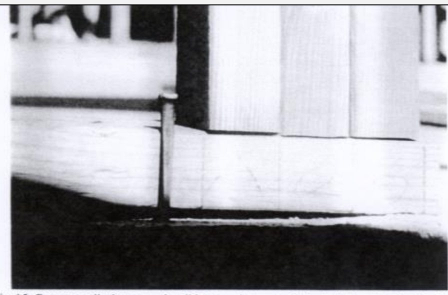


Fig. 15. Concrete nails that secured wall bottom plates extended only 1.3 cm into the foundation. Such nails were utilized in lieu of anchor bolts or metal straps in both new construction as well as in houses built prior to the tornado.

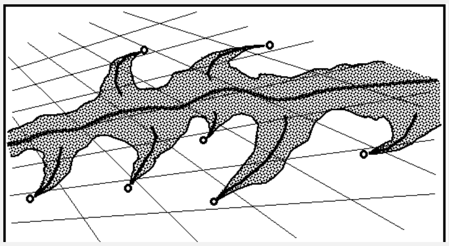
These two images show assessments on building performance that occurred after the Oklahoma City tornadoes. They focus on how the wall is connected to the bottom plate, and how it is ultimately anchored to the foundation in these two examples.

In south Oklahoma City, the Council of American Building Officials Code is used, which typically requires the floor to be anchored to the concrete foundation. The image on the left shows an example of that, which is a very good connection between the wall and the foundation. The problem is that there are other aspects of the way that buildings are constructed that do not enable that to be utilized. The wall itself is just straight nailed to this bottom plate, so there are just two nails that you can see sticking up that were holding the wall onto this bottom plate that was bolted. And that can immediately get wiped away in a tornado. It does not take F5 winds to completely destroy a building. Ultimately, those bolted connections did not have any benefit.

Despite this code, it was very rarely enforced. In fact, local municipalities in some areas, including Moore, OK, were less stringent in this CABO Code where they allowed the use of concrete nails and shot pins to connect to that foundation. When you use concrete nails, you get about a half-inch connection to the slab. If you are used to U.S. metrics, about the diameter of a dime is the only connection you have between your wall and the foundation in this case. And if you have ever nailed to concrete, often you are not going to get a really firm anchorage between a nail and concrete. The concrete often chips or cracks, leaving a weak connection. In this situation, it does not take F5 winds to blow a building away because it has a poor connection to the foundation. This was often found to be the case in Oklahoma City after that tornado occurred.

DEBRIS DAMAGE: TORNADO VS. HURRICANE

- Tornadoes contain more debris, particularly for locations experiencing low wind speeds (due to proximity to higher wind speeds within tornado path).
- It has been suggested that entire communities need to be resistant to tornadic winds to gain benefit from construction enhancements.



(left) Schematic illustration of cones of damage from windborne debris.
(right) Damage to glass due to windborne gravel from nearby commercial roofs.

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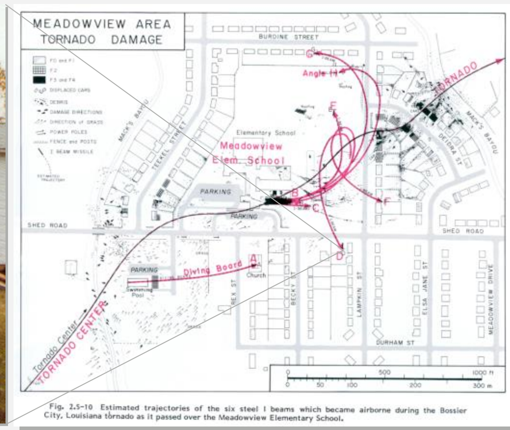
When tornadoes hit a suburban or urban area, they create a huge amount of debris. It is the swirling vortex of high winds that can create this lofted debris. It can have very long, swirling trajectories, and it can impact buildings and cause significant damage to a building envelope. When the building envelope is damaged, it then allows the internal pressure to increase and creates failures that otherwise might not occur if that debris had not hit the building.

The image on the lower left shows the debris patterns seen on the ground. Although the tornado path goes from left to right, you can see spires of damage that extend out from the center of the tornado path and reflect areas of high debris that are lofted and projected out from the center of the tornado rather than areas of higher wind speed. Think of each of these spires as being a weak subdivision of homes that are impacted. A large amount of debris is lofted and launched to the south hitting the properties. These properties might be constructed very well but they are not built to withstand the impact of two-by-fours into the side of the home.

When the May 3, 1999 Oklahoma City tornado assessment was done, the focus in the engineering community was not so much on how we can make one individual home wind resistant, but rather how can we make communities or neighborhoods wind resistant. How well your building performs is important, but so is how well the homes of your neighbors are constructed. How well they perform is also important because your building could get hit by their debris. This relates to mitigation credits and how tornado vulnerability is thought of from a modeling point of view. It does not make a lot of sense to give mitigation credits for tornado wind risk at one location because ultimately that risk is not only dictated by how that building is developed but also how its neighbors are developed and the construction standards applied.

The image on the right is a dramatic example of this from Fort Worth in the late 1990s, where a high-rise building with custom-made glass happened to be upwind from a mid-rise building with a gravel roof. It was not the winds that caused the damage, but rather all the gravel blown off its neighbor's roof that caused the damage. This was ultimately a total constructive loss because of the amount of value in the glass that was lost.

EXAMPLE OF TORNADO DEBRIS IN LOW WIND SPEED AREAS



Maps and photo from
Memoirs of T. T. Fujita

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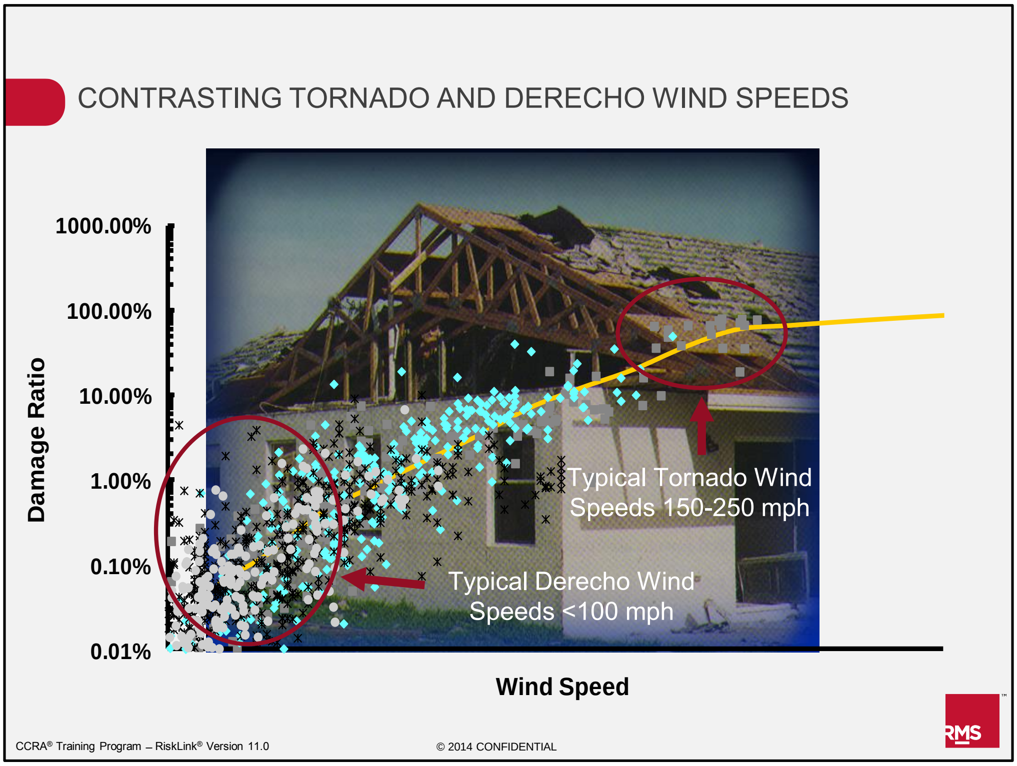
The image on the right is the path of a tornado as it went through a town in Louisiana. It hit an elementary school, which is labeled B and C on the map. The gymnasium was a steel-frame gymnasium, and its construction included eyebeams. When the tornado hit the gymnasium, it lofted and launched these eyebeams in very curly or arced trajectories to different locations, affecting property even though the wind speed was very low.

The image on the left highlights this. There is not much roof damage to this residential home, indicating the winds were not high at that location. You can see that the power lines are still up on the left. But this eyebeam was launched out from that school into the lawn next to the house. That kind of debris environment is very distinctive and different for a tornado than what you would see in a hurricane.



Next we will contrast tornado vulnerability with that of straight-line winds.

This image is one from insurance claims that show the damage ratio or the percentage of loss as a function of wind speed for some hurricane events. Hurricane damage ratios are very similar to what you would expect from a straight-line windstorm. The debris characteristics would be similar between the two; whereas in a tornado they would be somewhat different. Given the same type of building and the same construction standards, the use of claims information from hurricanes relates easily to understanding straight-line wind vulnerability.

When we look at any one vulnerability function, it is interesting to focus on the wind speeds that are common to a tornado versus those that are common to a derecho or straight-line windstorm. The peak wind speeds that have ever been observed in a straight-line wind event are a gust of 125 miles per hour. So most of those events occur on the far left side of this exhibit, where the damage ratios are very often less than 10% or even less than 1% on average. For a tornado, where the wind speeds are much greater and there is a greater amount of debris lofted and maintained within that vortex, the damage ratios tend to be much higher, often 15% to 100% damage ratio levels for a tornado.

CONTRASTING DERECHO AND TORNADO WIND SPEEDS

- Different predominant failure modes
- With greater amount of debris and greater wind speeds, different construction characteristics increase resistance to tornadoes as compared to straight-line winds.
- For tornado:
  - Roof anchor, roof geometry, and wind resistance of window openings are very important.
- For straight-line winds:
  - Architectural elements, for example, would be more relevant due to the predominance of low wind speeds contributing to the risk.

Because the damages tend to occur at different wind speed ratios, there are different building attributes that relate to the performance of a building in a tornado versus that of a straight-line windstorm.

For a tornado, it is not only how well that one building is constructed but also how well all of the neighboring buildings are constructed. If we consider that an entire community or subdivision is built to a high construction standard, attributes such as roof anchor, roof geometry, and the impact resistance of windows become important for how those buildings will perform. Those are attributes, or secondary modifiers of construction, that tend mitigate damage at high wind speeds.

In most cases, straight-line windstorms are not going to reach a wind speed range where those attributes are going to become critically important. Most of the attributes that relate to straight-line wind performance are architectural elements such as porches, or how awnings or eaves are constructed and how that might relate to damage. Therefore, it is the architectural elements of a building that often are affected in a straight-line windstorm.

Capturing those architectural elements when running the model for an average annual loss analysis in the upper Midwest, for example, is important because that is a region where straight-line winds play a significant role in the annualized loss. So, having that data on those buildings is important. For tornadoes, that would be much less relevant.

CONTRASTING HAIL AND WIND VULNERABILITY

- Hail
  - Vertical (impact) force
  - Typical building damage ratios <10% for hail
  - Higher damage ratios for autos
- Wind
  - Lateral (dynamic pressure) force
  - Lateral (impact) forces from debris/missiles
  - Typical building damage ratios:
    - 50% or more for an intense tornado
    - <10% for straight-line winds

Next we will talk about hail vulnerability and how impact resistance of the different products relates to the vulnerability from hail. We will also contrast the forces from hail versus the forces from wind.

We have talked about wind as having a lateral force where there is a dynamic pressure from the wind. There can also be a lateral force that is impact-related from debris and missiles that are launched from a tornado. We also gave a sense of the typical damage ratios for those types of hazards.

Hail is somewhat different. There is a vertical impact force from the hailstones that are falling and perhaps being driven by the wind, and so their associated damage ratios tend to be relatively small. They tend to relate to the portion of the home value that the roof has relative to the total value of the home or the cladding, as on the exterior of the building. You can use a relative percentage of the building's exterior to the total value of the home as a metric on what types of hail loss you might see in any one location.

The damage ratio to autos can be higher, which often results in a vehicle needing to be salvaged. That damage ratio is often capped at about 50% or the level at which a salvage is established for a given automobile.

KEY COMPONENTS OF HAIL SEVERITY

- Hailstone diameter
  - Energy from terminal velocity
- Wind speed accompanying hail
  - Increases the hailstone fall speed and introduces a horizontal component to its motion
  - As the winds accompanying hail increase, a golf ball size hailstone can have the effect of a two inch or greater hailstone, which has approximately twice the impact energy of a golf ball.
- Number of hailstones per unit area

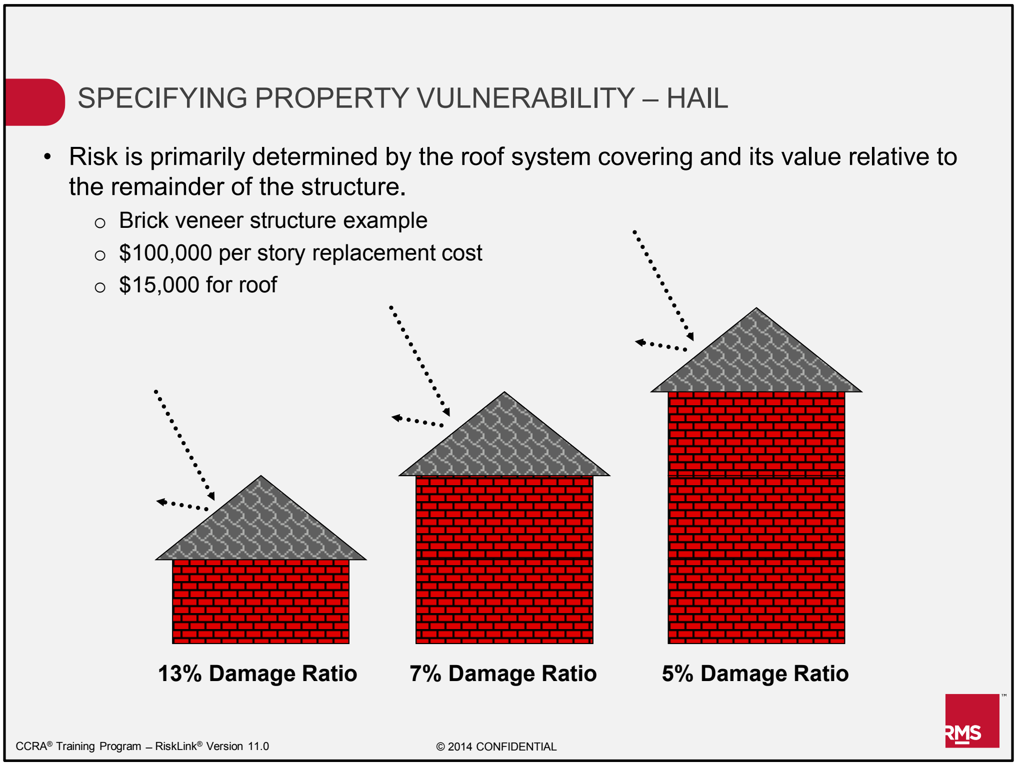
Similar to how we talked about the Fujita Scale for tornado intensity, we want to frame the key components of hail severity.

First is the diameter of the hailstone, followed by the wind speed that accompanies that hailstone as it falls at its terminal velocity. That wind speed will both increase the fall speed of that hailstone and also give a horizontal component to its motion so it can not only affect the roof but also walls and other things that might be protected from a stone falling directly downward. If it has an angle to its movement, it could affect walls and damage vinyl siding or break large windows.

The wind is an important component because when it accelerates, the movement of a hailstone increases the impact energy. For example, a golf ball size hailstone, which would be about 1½ inches in diameter, can actually have the effect of a 2 inch or greater hailstone because the wind is also driving it and increasing its speed. That is about twice the impact energy for that size hailstone. So the presence of wind in a hailstorm is very important to the damage that can be caused.

The final component that relates to the intensity of hail and how it might be considered in a model is the number of hailstones per unit area. If there is a very small number of hailstones that are large in a given square kilometer, they can produce much less damage than if there are hundreds or thousands of those large hailstones per square kilometer.

Each of those components are considered in the simulation of hail hazard in a catastrophe model and need to be considered when assessing damage and risk to an individual property.



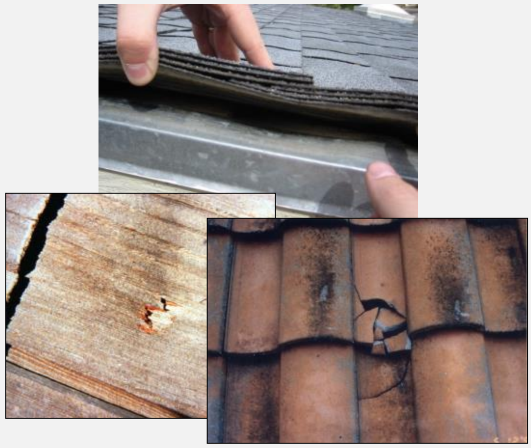
When we look at damage ratios due to hail, one of the key things we want to highlight is that it varies significantly with building height. This is because the roof covering is the primary source of loss from hail, and its relative value as a percentage to the total building value will decrease as the building height increases.

Let us assume that a house has a value that varies linearly with each story, which is not completely realistic but is reasonable, and that the roof is worth 15% of the value of each story. So if each story of the house is worth $100,000 and the roof itself is worth $15,000, we can then calculate the damage ratios that would be experienced if the entire roof was lost. For a one-story building, we would see a damage ratio of about 13% if the entire roof needs to be replaced. As the building height increases, the damage ratio decreases so it might be 7% for a two-story and 5% for a three-story.

This is not the exact process that we go through in developing vulnerability functions, but it is very similar to the type of calculations that are used when establishing relativity between a low-rise wood frame vulnerability and a mid-rise wood frame vulnerability.

SECONDARY DRIVERS OF HAIL DAMAGE

- Property Exposure
  - Roof system covering
  - Roof age
  - Cladding type
  - Skylights (with or without cover)
  - Impact resistance of windows



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Since roof covering is the most critical element for hail vulnerability, the characteristics of that roof covering are a key determinant in how that building will perform and, ultimately, what its risk is due to hail. Also, since a substantial amount of the average annual loss is driven by hail, this is a very relevant and very important characteristic. Again, the average annual loss for severe convective storm is roughly $6 billion in the U.S. with almost $4 billion of that driven by hail. The roof covering, its age, and other information about it is very relevant for the consideration of mitigation credits, or credits that would be provided toward premium based on the type of roof covering that an individual homeowner or a commercial business has.

Cladding type also is very relevant. It is probably second on the list of critical elements after the roof covering. If a home has vinyl siding versus brick veneer exterior, it can have very different vulnerability characteristics to hail. Skylights and the impact resistance of windows are also very relevant.

BUILDING CODES

- Four major codes have recently included provisions requiring roofing systems to meet minimum impact resistance requirements:
  - BOCA National Building Code (BOCA)
  - Standard Building Code (SBCCI)
  - South Florida Building Code (SFBC)
  - International Building Code (IBC) - Installing asphalt shingles over existing roof systems is not permitted in areas subjected to severe hail damage where IBC code is enforced

Next, we will focus on roofing material because that is the most prominent and most important aspect of mitigation credits due to hail.

There are a number of different building codes that reflect provisions on or requirements surrounding roof-system covering that are used to meet various impact-resistance standards. Those codes are becoming more prevalent in and among states that require certain impact-resistant capabilities of the roofing products that are used.

The International Building Code has requirements around the roof system itself and its impact resistance. It also states a roof should not be installed on top of an existing roofing system because it reduces the performance of that roofing product. For example, if a homeowner has an asphalt shingle roof that weathers significantly and needs to be replaced, often a roofing contractor will just put another roof covering directly on top of it without removing the old one down to the decking.

When they do this, it can increase the vulnerability significantly. If you take a sheet of paper, lay it on a table and throw a rock at it, the rock will bounce right off because the paper has a strong backing, the table. If you hold that piece of paper up tightly and then throw the rock at it, the rock will puncture right through because there is no strong backing. When multiple roof coverings are installed on top of one another, the strength of that backing has essentially been removed. This is why the vulnerability is substantially increased when a roof is installed in that manner rather than directly to the underlying decking. So, not only is the roof covering itself and its age important, but also how it is installed. Installing the rood covering directly on the decking versus over an existing roof system relates to its vulnerability.

VARIATION IN VULNERABILITY BY ROOF COVERING

- 3-tab shingles are commonly used and the least resistant to hail.
- Roof coverings common to commercial buildings, such as built-up gravel, are very impact resistant.

% Damage to a Single Shingle by Roof Type from Engineering Tests

Type of Roofing Product	Age (yrs)	1 in. (25 mm)	1.25 in. (32mm)	1.5 in. (38mm)	1.75 in. (44mm)	2.0 in. (50mm)
3-tab fiberglass shingles	11	0	60	90	100	100
3-tab organic shingles*	11	50	90	100	100	100
30 yr. Laminated shingles	11	0	0	60	90	100
Cedar shingles	11	0	30	80	100	100
Heavy cedar shakes	0	0	0	50	90	100
Fiber-cement tiles	0	0	20	80	100	100
Flat concrete tiles	0	0	20	50	50	100
S-shaped concrete tiles	0	0	0	0	0	80
Built-up gravel roofing	8	0	0	0	0	30

- Texas DOI requires residential premium credits for building owners and homeowners of up to 35% for using roof systems that meet impact resistance requirements.

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RMS

When applying a model or applying mitigation credits due to hail risk to establish residential or commercial rates in various states, the type of roof system covering that would be present on a home is very critical.

This slide gives an example from an engineering point of view of how different roof shingles or different products perform under various hail sizes.

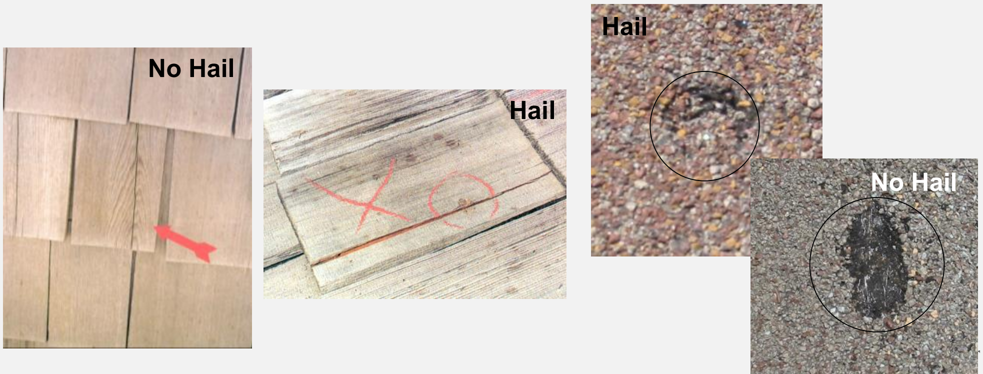
On the table in the middle of the slide, various roofing products are listed. On the right are hail sizes ranging between one inch and two inches in diameter. If we look at the one inch column we see that there is only one type of roofing product, a three-tab organic shingle, where any damage is present for a one inch hailstone. So that is roughly the hail size threshold for property risk assessment that is relevant.

We can use this table to rank different roofing types based on their performance and determine which ones would have a mitigation credit and which ones might have a penalty.

Three-tab organic shingles and laminate shingles belong to a group of products that are often referred to as an asphalt shingle. Those tend to perform the worst. Cedar shakes or a wood type of roof tend to be in a middle category and a built-up gravel roof, concrete, or slate tile roof tend to perform the best. These are some rough categories one can use to understand the relative performance of each of these roofing products. This is becoming more and more important as departments of insurance begin to require insurers to provide credits to homeowners and building owners that have hail-resistant roof systems in place. Texas is one of the key states that currently has a requirement around that.

CONSUMERISM AND CONSERVATIVE LOSS ADJUSTMENT

- My neighbor got his roof replaced, why shouldn't I?
- When in doubt, give the benefit to the consumer.
  - Anecdotal evidence ~50% overpayment of insurance claims relative to engineering assessments of damage for some past events.



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RMS

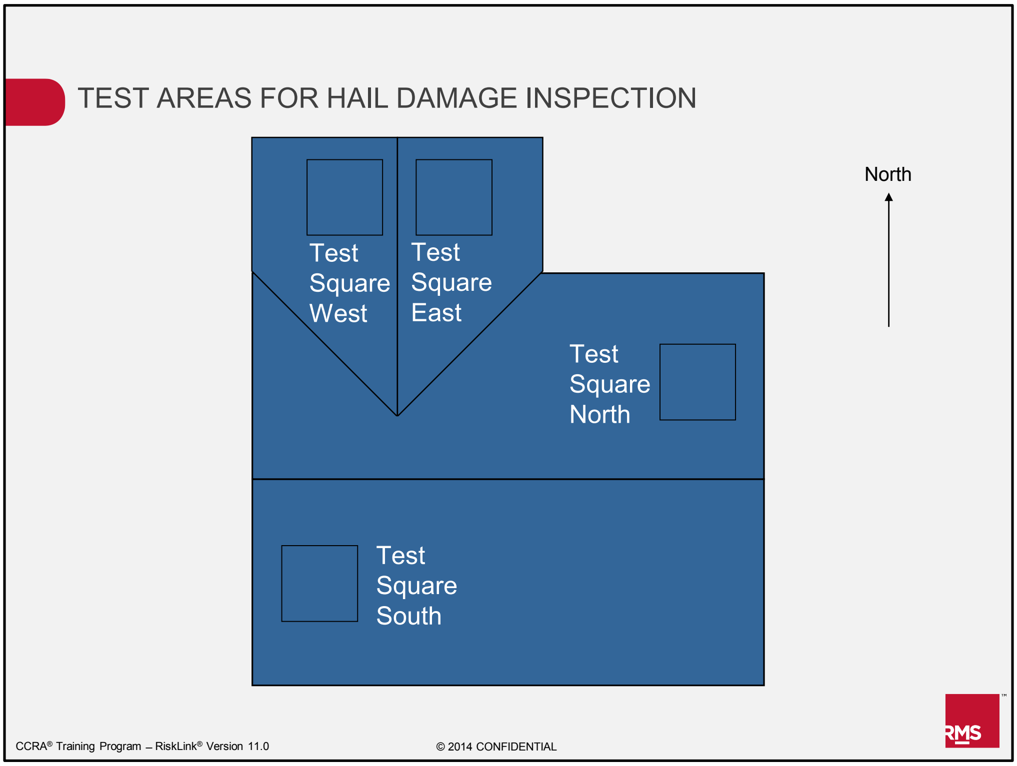
Some of the other aspects relating to hail vulnerability that are important to recognize are less tangible. They are not directly from an engineering point of view but relate to how that hail damage is assessed and adjusted from an insurance point of view.

The hail peril is about the only catastrophic source of loss that produces damage that you almost need a microscope to assess. When you recognize hail damage and you want to try to differentiate it from other types of roofing marks, you need a lot of training and a significant level of expertise to understand what has actually occurred.

For example, if we look at the photo on the left, to the untrained eye it is not immediately obvious how that split shingle and the split shingle in the middle photo are different. In the photos on the right, it might not be immediately obvious why one of these damage marks would be from hail and the other would not.

When losses are adjusted, it requires a very keen eye and good training to understand whether or not it actually is hail damage, particularly with the aggressive nature of roofing contractors and because homeowners may become interested in filing claims if there has been hail damage in a location near them. The first claim that gets paid in a neighborhood can be the most critical because it essentially sets a precedent for the type of damage that occurred in that region.

The difficulty in recognizing damage coupled with loss adjusters that may not be very well trained can lead to claims being paid for roof damage that is not caused by hail but by roofing contractor footmarks, natural weathering, or the damage may even be fraudulent. Anecdotal evidence from engineers that have focused on this problem have shown, from their point of view, there can be up to 50% overpayment of insurance claims due to incorrect recognition or incorrect payment of hail damage to residential roofing products. And so how the loss is adjusted is, from their point of view, a very significant driver of catastrophic loss. This needs to be considered when calibrating a model to past insurance claims.



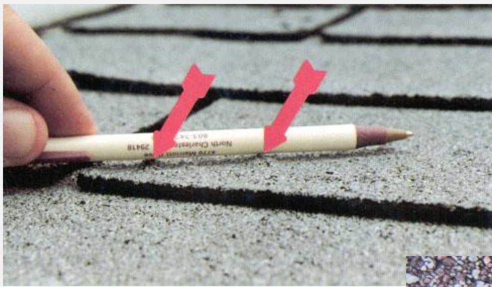
This slide is a quick survey of what a loss adjuster does when looking at a building. The adjustor establishes test squares on different faces of the roof and then counts the number of damage marks on each of these test squares. If there are seven or more damage marks within a region, for example, the roof will be replaced.

COMPOSITION ROOFS: EFFECTS OF WEATHERING

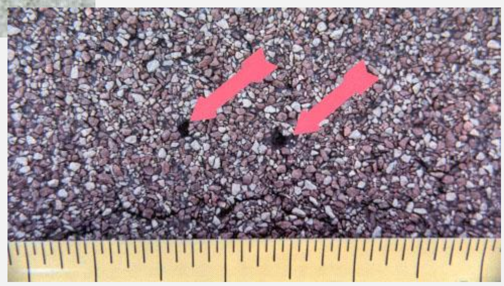
- Granule loss of composition (aka laminate) shingles is generally due to weathering and foot traffic, and not a sign of functional damage from hail impact.

The loss of granulars or some of the covering on top of the tar paper on the roof can be misrecognized when assessing a roof for damage. In the photo on this slide you can see some accumulation of that in the gutter. It is sometimes thought that this can reduce the life expectancy of the roofing product and constitute damage that needs to be paid, but in fact it does not have any functional damage to the roof.

COMPOSITION ROOFS: MANUFACTURING DEFECTS



Blistering



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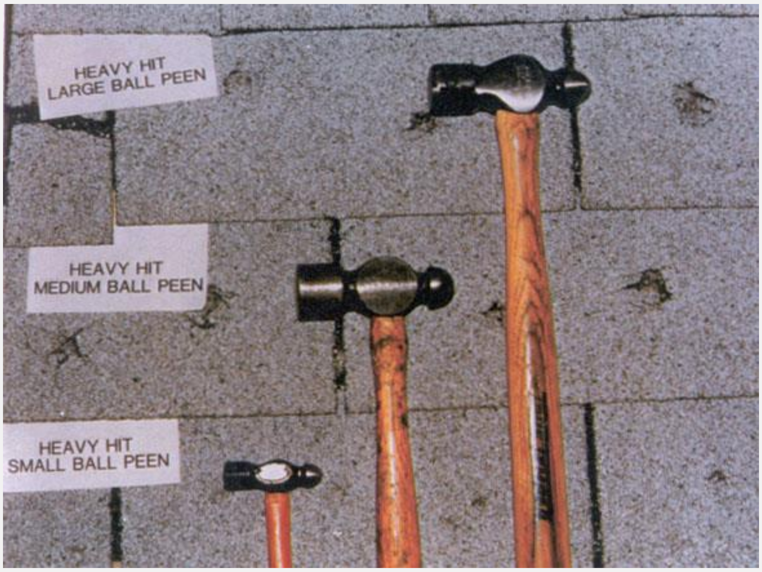
Other things, like the blistering of shingles or raised marks that occur over time from weathering and cracking of shingles, can be misconstrued as hail damage.

COMPOSITION ROOFS: DAMAGE CAUSED BY HAMMERS



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Then there are fraudulent situations where damage marks are created using a hammer on a roof. Even more common is a contractor dropping his hammer when installing a roof and a mark can be left on the roof. Later, when the hailstorm occurs, that can be misconstrued as damage due to hail.

REGULATORY ACTIONS INFLUENCING HAIL VULNERABILITY

- Legal precedent requires insurers must make repairs with matching materials. (e.g., Minnesota and Missouri)
  - "Companies that refuse to replace siding (or compensate for damage to siding where coverage is under a standard fire dwelling policy), except on the side actually damaged by hail, may not have fully considered Section 375.1007(4), RSMo (2000)."

There are some important regulatory factors that influence hail vulnerability in the scale of catastrophic loss, and these provisions in some states relate to how the repairs are made. In some states repairs must be made with matching materials and if matching materials cannot be found to make a repair, then an entire replacement of that product is required.

For example, if vinyl siding has faded and then gets dented from hail, though only one side of the home is dented, the entire house's siding might need to be replaced because the color no longer matches. Those types of provisions are common in some states where major catastrophes have happened in the last decade. Minnesota and Missouri are two prominent examples where that has occurred and is now in force. In Missouri, in particular, the vinyl-siding example became very prominent.

This is additional information that needs to be considered when calibrating vulnerability functions using actual insurer claims experience to reflect the types of actual losses that would be incurred in an event in the future.

BUILDING EXPOSURE VS. MOTOR EXPOSURE

- Property Exposure
  - Static Exposure
- Motor Exposure
  - Location Dependent
  - Time Dependent

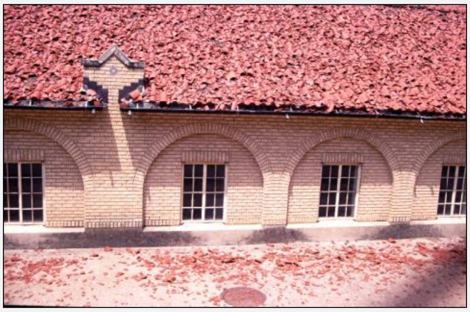


Photo Source: Haag Engineering

Photo Credit: J. Imel/Park City Daily News

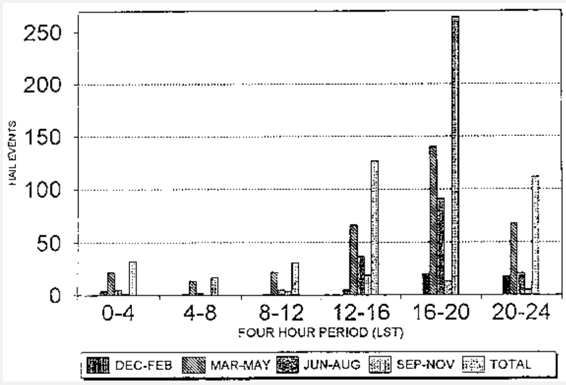
Next we will talk briefly about automobile vulnerability and contrast that with building vulnerability, as well as talking about different types of automobile risk.

The key difference between automobile exposure and property exposure is that automobile exposure is not static. In other words, personal automobiles or commercial fleets may be moving all day or may be parked for part of the day. Their geographic position changes over time so they can become more or less concentrated or more or less correlated as a function of the time of day.

You may be familiar with some of the other RMS models, such as the casualty model, where mobile exposures are considered. Human exposures are mobile during the working hours, for example, where there is an influx of individuals to a city center. There is a high correlation of the human population in that city center during the day and then it becomes more distributed overnight. The correlation changes as a function of time. That occurs similarly with vehicles, depending on the time of day. The correlation of those vehicles can change as a function of time.

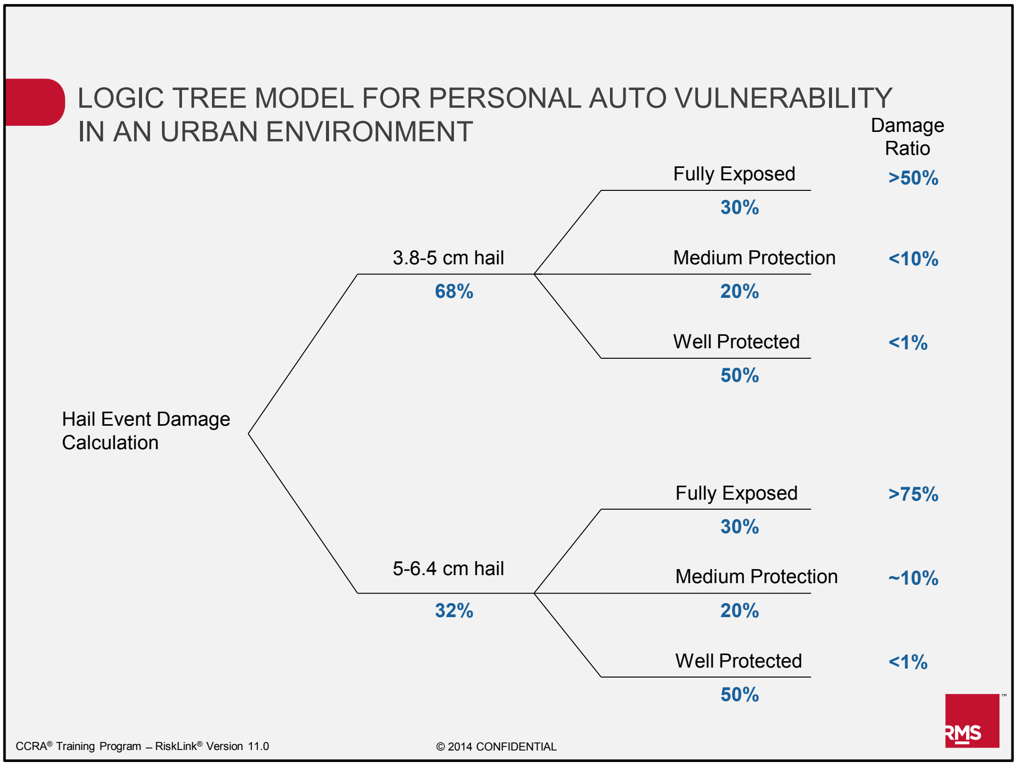
DAILY CYCLE OF HAIL OCCURRENCE

- Unlike a workers compensation risk assessment for earthquake, hailstorms occur at predictable times of the day and, therefore, logical arguments can be used to specify the exposure of automobiles to hailstorms (rather than random simulation).



One of the key distinguishing features between the casualty and the automobile examples are that for casualty earthquake risk assessment, an earthquake can happen at any time. The time of day when hail would occur is more predictable. Hailstorms are prevalent in the late afternoon hours, and so the hail occurrence has a specific probability associated with it as a function of time.

The graph on the slide illustrates this point. You can see that most reports of hail are given in the 16 to 20 hour window. Because of this, the assumptions that go into developing hail vulnerability can be simpler than what you might have for a purely random hazard like an earthquake for a casualty application. RMS uses logical arguments to establish the probability of different automobiles being protected and being in proximity to one another.



This is an example of what the logic tree approach looks like for personal automobile vulnerability. This logic tree is for an urban environment but could also apply to a suburban environment.

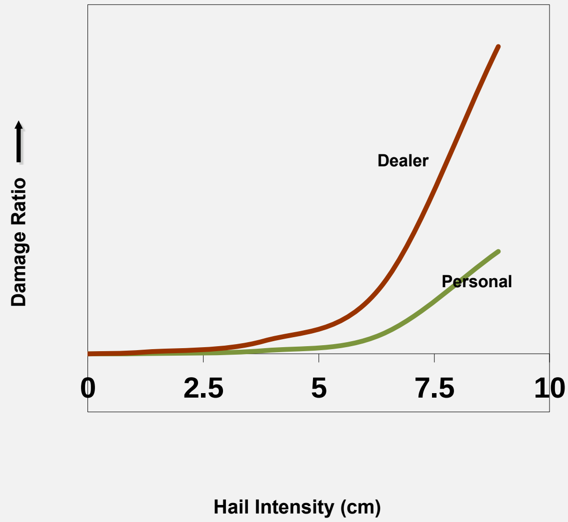
The approach to developing a vulnerability function for personal automobiles is to first develop a mean damage ratio for a specific hail size range.

In this case the range of hail sizes is between 3.8 centimeters (1.5 inches) and 6.4 centimeters (2.5 inches). If we are trying to establish a mean damage ratio for a 3.8 to 6.4 centimeters hail size range, we would look at the historic occurrence of hail within those two size ranges and see that a little more than two-thirds of hail within that range actually occurs in the lower half of that range (3.8 to 5 centimeters), whereas only one-third comes from the higher end of that hail size range.

Within each of those hail dent sizes, we can then establish the approximate percentage of automobiles that are either fully exposed, meaning they are parked in an area where they are not sheltered at all, those that might have partial protection, such as being under the awning at a gas station or under a carport, versus those that are well protected or fully protected, such as those that might be parked in a garage and have no probability of being affected by hail at all. From these we can define a damage ratio for that given hail size range at each of these different levels of exposure.

You can go through a similar process using the same exposure assumptions for the higher hail size range and then weight each of these damage ratios to arrive at one mean damage ratio for personal automobiles effective within this 3.8 to 6.4 centimeter hail size range.

CALIBRATION – HAIL VULNERABILITY MODELING



- Calibration with insurer data and relativities have been used to relate hail intensity to insurance payouts.

Open automobile dealer lots have different assumptions. In many ways, they are much simpler. Dealer open lots assume approximately 90% exposure, meaning there is only a small number of the automobiles that are protected within the showroom floor. Most vehicles are fully exposed on the lot. These different exposure assumptions between the two types of automobile exposure yield very different views of their vulnerability. Dealer automobiles are much more vulnerable to hail than personal automobiles.

How does RMS come up with these protection assumptions for the different vulnerability curves? Much of that information comes from speaking with underwriters or clients who focus solely on automobile risk. In particular, many of these conversations occur on the dealer side to understand the exposure assumption and to calibrate the damage ratio for that full exposure assumption with actual losses that were incurred from past hail events.

Because a dealer lot may have hundreds of different automobiles but all located in one location, it is important to model those hundreds of automobiles as one location rather than coding each automobile separately. Because they are located within the same lot, they are highly correlated. So coding those locations individually would overly diversify the risk and underestimate the modeled loss.

VULNERABILITY AND LOSS CALIBRATION

- Vulnerability involves analysis of:
  - Insurance claims data
  - Damage surveys
  - Engineering expertise
- Claims data have been analyzed to estimate mean damage ratio and uncertainty. Some major events analyzed include:
  - May 4, 2007 Greensburg, Kansas
  - April 13-15, 2006 Midwest
  - May 2-11, 2003 Plains/Midwest
  - May 3, 1999 Oklahoma City
  - May 15, 1998 Minnesota

We have talked about many different aspects of tornado vulnerability that are unique and distinct from hurricane in terms of debris. We have also talked about hail damage where there are insurance loss adjustment issues for aspects of performance between personal and dealership automobiles that are very distinct from what we might see from other hazards. It is important to calibrate RMS' views on vulnerability with actual loss experience for these reasons. It is as critical, if not more critical, for this peril than for others.

This slide lists a sample of the types of events that are focal points in that calibration process, some of which were mentioned in this presentation. Some of the other events are major hailstorms or major multi-day outbreaks that have been considered in the calibration process. When you evaluate a catastrophe model and look at how it is going to be applied, particularly to the severe thunderstorm peril, understanding the types of information that

UNIT 2: VULNERABILITY OF PERIL EXPOSED COVERAGE
LEARNING OBJECTIVES

- Structural characteristics that influence wind loss include a building's load path and the ability to both alleviate pressure and manage suction on the walls and roof.
- The Enhanced Fujita Scale is part of a newly refined method used to classify tornadoes and is based on the peak damage that is observed in the tornado's path.
- Tornadic storms contain large amounts of debris.
- Hail and straight-line wind storms typically see building damage ratios <10%. Hail storms typically see higher damage ratios for automobiles. Intense tornados can show typical building damage ratios at a level of 50% or more.
- Factors that impact the vulnerability curves for hail and inland wind perils include the role and impact of building codes, claims adjustment issues, and calibration using claims data.

This slide summarizes the key points from Unit 2. If any of these points are unclear, please revisit the associated slides within the unit. This concludes Unit 2 of the Severe Convective Storm Modeling Course.