

EVALUATION OF HAIL-STRIKE DAMAGE TO ASPHALT SHINGLES BASED ON



HAILSTONE SIZE, ROOF PITCH, DIRECTION OF INCOMING STORM, AND FACING ROOF ELEVATION

Hailstones from October 4, 2006, hailstorm in Gahanna, Ohio.

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ABSTRACT

This paper is based on six years of hail-strike inspections (729 total) of residential properties gathered by EES Group, Inc. The data collected were correlated to determine the following:

- Maximum likely size of hailstone compared to the number of hail-strike bruises,
- Roof pitch versus number of hail-strike bruises, and
- Bruise counts on roof elevations facing toward, away, and 90 degrees from the incoming storm.

From this work, EES found:

1. The estimated maximum size of hail must be between 1¼ inches and 2 inches in diameter to cause increased hail bruises per roof elevation (greater than ten hail-strike bruises per 100 square feet);
2. The bruise count vs. roof pitch suggests that shallow and steep roofs (defined as those measuring below a 4-in/12-in pitch and steeper than 9-in/12-in, respectively) had more hail-strike bruises than moderately sloped roofs (defined as roofs with 5-in/12-in to 9-in/12-in roof pitches);
3. The shingles on roof elevations facing toward an incoming storm contained almost 2½ times as many hail-strike bruises as roof elevations

facing away from the incoming storm; and

4. Roof elevations facing toward an incoming storm contained over two times as many hail-strike bruises as roof elevations perpendicular to the incoming storm.

EES data demonstrate that there is a strong correlation between hailstone damage and the size of hail, the pitch of a roof, and the direction a roof faces compared to the direction of an incoming hailstorm.

REVIEW OF BACKGROUND LITERATURE AS IT APPLIES TO THIS STUDY

Hail-impact damage has been the subject of many studies over the past 55 years. The first published ice impact studies were conducted by Rigby and Steyn⁶ in 1952. Since then, many test methods have been created, implemented, and published to replicate hail impact damage to various building surfaces, from asphalt shingles to metal roof vents. Researchers have also tried varying the size of synthetic hail in these tests in an attempt to determine the hail damage threshold of asphalt shingles. Other key variables include the velocity at which the hail travels, the angle of impact between the hail and the roof elevation, and the effect that wind has on the velocity—all of which are factors on the impact force of a hail strike.

In 1969, while working for the National Bureau of Standards, Greenfeld³ published a report that stated that at hail's terminal freefall velocity, damage to asphalt shingles occurred when hail measured from 1½ to 2 inches in diameter. These data were found by launching freezer-made ice stones at test panels. Greenfeld³ also explained how ice is formed in alternating layers of milky ice, which has a lower density than freezer-made ice. Therefore, the simulated ice stones are of higher density and weight than actual hailstones of the same size. Thus, he indicated that simulated hail may overestimate or conservatively estimate actual hail damage.

In 1991, Koontz⁴ published a paper on ice-impact damage, which took into account the effects of wind on the impact force of hail. He came to the conclusion that the vertical free-fall velocity of hail, combined with the horizontal velocity of the wind, creates a greater impact force than that of free-falling hail. This was proven by Koontz using trigonometry and the addition of vectors. He also proved through mathematics that the impact force of hail increases exponentially as the mass and velocity of hail increase.

In his 2001 publication, Noon⁵ devoted a chapter to the effects of hail on a roof. Noon⁵ reported that the damage threshold for asphalt shingles is two inches in diameter for roofs that are constructed of quality materials and are properly installed. Noon

also found mathematically that hail-strike damage increases as the angle which the hail strikes the roof nears 90 degrees (i.e., perpendicular strike). He also reported that hail striking soft metal surfaces leaves dents up to half the size of the hail that struck the subject residence. Thus, one can estimate the maximum size of hail that struck a building's finished surfaces by doubling the size of the largest hail-strike dents observed on soft metal surfaces such as box vents, gutters, and downspouts.

Haag Engineering^{1,2} has published numerous reports concerning the effects of replicated hail on composition (asphalt) roofing and other exterior finishes. Haag's first major hail publication was in 1975 and contained the findings of its study on red cedar shingles.² Since then, Haag Engineering has become the industry leader on hail damage testing, including a paper of particular interest published in 1993¹ on hail damage to composition shingles. Its findings include a chart that compares size of ice stones to the weight, freefall velocity, and energy of the corresponding ice stones.

The major objective of Haag Engineering's testing was to find the amount of hail damage to shingles and metal roof vents at the terminal freefall velocity of hail. This was accomplished by launching freezer-made ice stones at perpendicular angles to the composition roof panels and metal roof vents. The findings showed that replicated hail, measuring up to 1/2 inch, would cause noticeable dents to soft metal apparatuses, while the same size ice stones were not yet large enough to damage composition roofing on a consistent basis. When the replicated hail reached 3/4 inch in diameter, the ice stones caused damage to deteriorated and unsupported composition shingles. When the replicated hail reached 1 inch in diameter, the ice stones caused damage to lightweight shingles, whereas heavy composition shingles were damaged when replicated hail reached 1 1/4 inch in diameter.

DESCRIPTION OF HAIL DATABASE

EES Group, Inc. has compiled a database containing information gathered during hail-strike damage inspections in Ohio

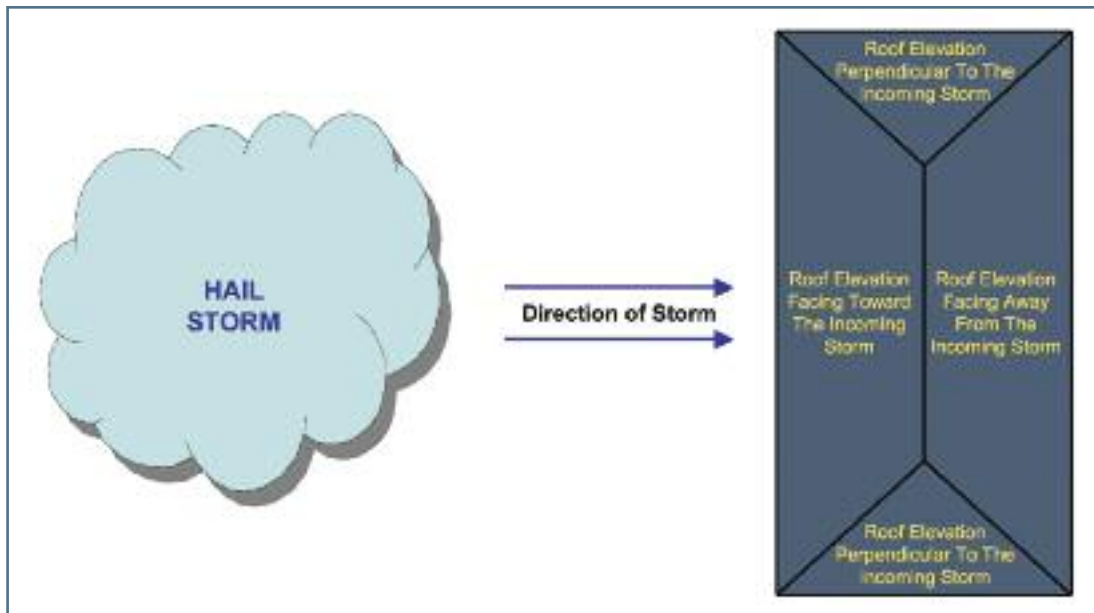


Figure 1- Direction of arriving hailstorm vs. roof elevation.

and West Virginia from June 2002 to August 2007. The database used for this paper included 729 hail damage inspections on asphalt-shingled roof surfaces. This study only included those roof elevations that showed no signs of degradation and fell within their designated lifespan. The inspections were performed primarily by three hail-damage inspectors who were engineers with many years of roof inspection experience.

CORRELATION RESULTS

Based on detailed data collected on the 729 site inspections over the five-year period, EES Group, Inc. correlated the data to determine the following:

- Size of hail vs. bruise counts to asphalt shingles,
- Bruise count vs. slope of roof,
- Bruise count on roof slope facing the

hailstorm vs. count on opposite face, and

- Bruise count of roof slope facing the hailstorm vs. count on perpendicular faces.

Note that the last two correlations (see Figure 1) may be useful to degraded roof surfaces not suitable for bruise counts, which, according to our study, often face south and west into the direction of arriving hailstorms.

A summary of the results of these correlations follows:

Correlation 1: Hail Size Compared to Hail-Strike Bruise Counts

For this correlation, the hail-strike damage inspection database by EES Group, Inc. was manipulated to include only inspections containing roof elevations covered

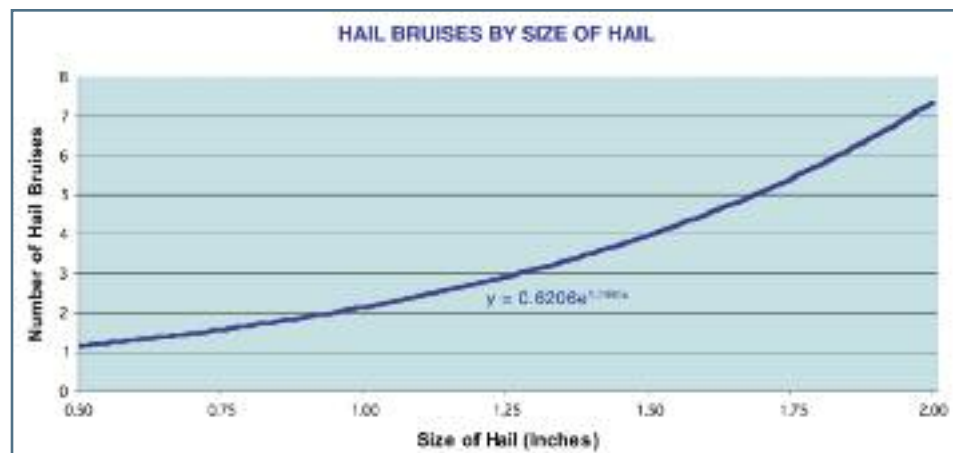


Figure 2 - Hail bruises by size of hail.

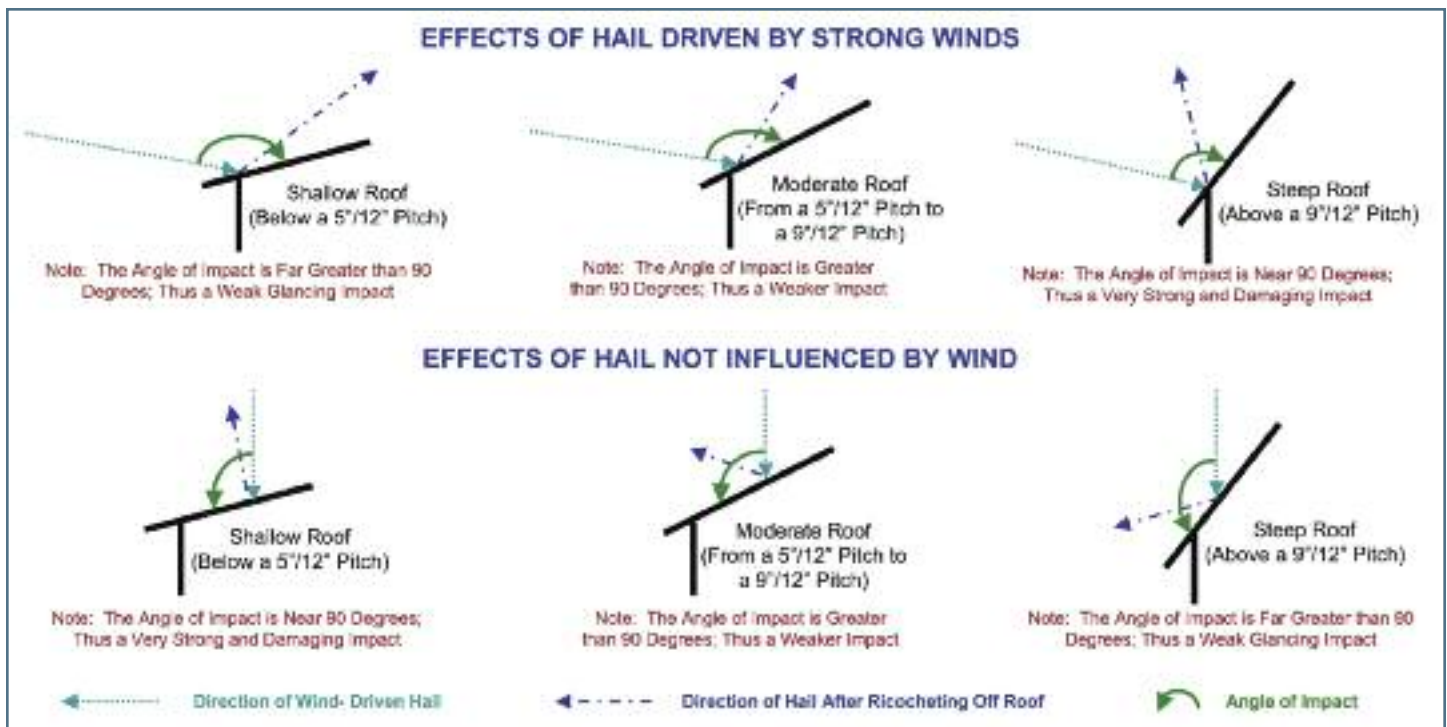


Figure 3 – Hail direction vs. roof pitch.

ROOF CATEGORY	ROOF PITCH	ACTUAL BRUISE COUNT/ EXPECTED BRUISE COUNT RATIO
Shallow	Below 5-in/12-in pitch	179%
Moderately Shallow	5-in/12-in to 6-in/12-in pitch	56%
Moderately Steep	7-in/12-in to 9-in/12-in pitch	74%
Steep	Above 9-in/12-in pitch	152%

Table 1: Bruise counts by roof pitch.

with asphalt shingles and showed hail-strike dents on soft metal surfaces (597 sites). As determined by Noon,⁵ hail size is typically at most double the largest hail-strike dent found on the soft metal fixtures of the home. Using Noon’s method, the maximum hail size that likely struck each subject residence was determined in all cases.

Remaining data sets were broken down into hail-size subgroups of 1/8 in to 3/4 in, 7/8 in to 1 in, 1-1/8 in to 1 1/2 in, 1-5/8 in to 2 in, and greater than 2 in. Similarly, the bruise counts per 100 sq ft were collected from measured field values. Using this information, a scatter plot graph was created by placing the mean hail size for each subgroup on the x-axis and the mean number of bruise counts on the y-axis. Using this data, the number of hail bruises was found to increase exponentially as the size of the hail increases (Figure 2).

Correlation 2: Pitch Compared to Hail-Strike Bruise Count

This correlation used the formulas and data found in Correlation 1 along with pitch information gathered during the original hail-damage inspections. As shown in Figure 3, hail could fall vertically if local wind conditions were light or came in from a more horizontal direction if winds were stronger. Therefore, damages to the inspected roofs can vary, depending on the pitch of the roof and angle at which hail strikes the roof.

The hail-strike damage inspection database by EES Group, Inc. was manipulated by removing all hail strike inspections that did not include pitch information about the subject roof elevations. This left 837 individual roof elevations (from ~350 separate sites). Taking into account the size of hail that struck the subject roof elevations and the number of hail strike bruises, EES then determined the number of hail-strike bruises

es that one would expect to find per 100 sq ft. Next, the actual number of hail-strike bruises in the corresponding areas was found, and this number was divided by our estimates to give a percent ratio. Any ratio above 100% contained more hail bruises than one would expect to find. Those ratios below 100% had less hail-strike bruises than one would expect.

Findings were then placed into four groups:

1. Shallow roofs, composed of roof elevations with slopes below a 5-in/12-in pitch;
2. Moderately shallow roofs, composed of roof elevations with slopes from 5-in/12-in to 6-in/12-in pitch;
3. Moderately steep roofs, composed of roof elevations with slopes from 7-in/12-in to 9-in/12-in pitch; and
4. Steep roofs, composed of roof elevations with slopes above a 9-in/12-in pitch. Table 1 presents the findings for this correlation:

EES’s findings clearly show that roof elevations with a low pitch and roof elevations with a steep pitch sustained far more hail damage than would be expected – 179% and 152%, respectively. On the other hand, the moderately shallow roof elevations and those with moderately steep roof elevations contained substantially less hail damage than would be expected, 56% and 74% respectively. One explanation for this result

may be that hailstorms typically have either hail falling essentially vertically or hail that is heavily wind-driven.

Correlation 3: Hail Damage Sustained by the Roof Elevations Facing the Incoming Storms Compared to the Roof Elevations Facing Away from the Incoming Storms

For this correlation, the hail-strike damage inspection database by EES was manipulated to include only roof elevations finished with asphalt shingles. This correlation focused on comparing the amount of damage received by roof elevations facing incoming hailstorms to roof elevations facing away from incoming storms. See *Figure 4*.

The number of hail-strike bruise counts for each test area was then manipulated to determine the number of hail-strike bruise counts per 100 sq ft. The average number of hail-strike bruises per 100 sq ft for all elevations facing into incoming hailstorms was then calculated. This process was repeated for all roof elevations facing away from the incoming storm. The number of hail-strike bruises on the roof elevations facing toward

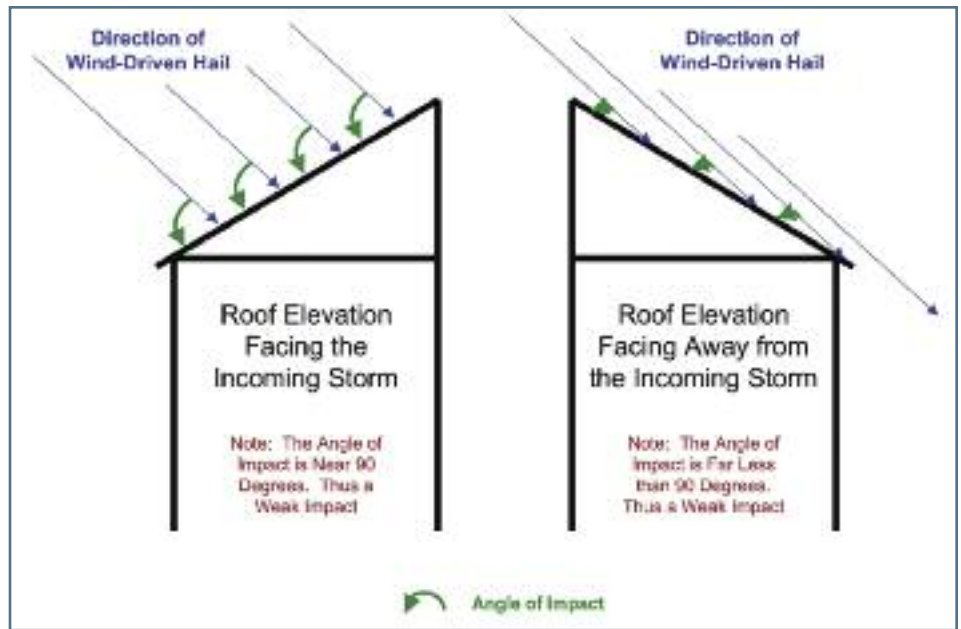


Figure 4 – Hail impact on roof facing incoming storm and roof facing away from incoming storm.

the incoming storm was then compared to the number of bruises on the roof elevations facing away from the storm and turned into a ratio. Using results from 51 site inspections, the study found this ratio to be 2.4:1

(see *Figure 5* and *Table 2*). Thus, a roof facing the incoming storm had bruise counts nearly two and a half times that of the roof elevation facing away from the incoming storm.



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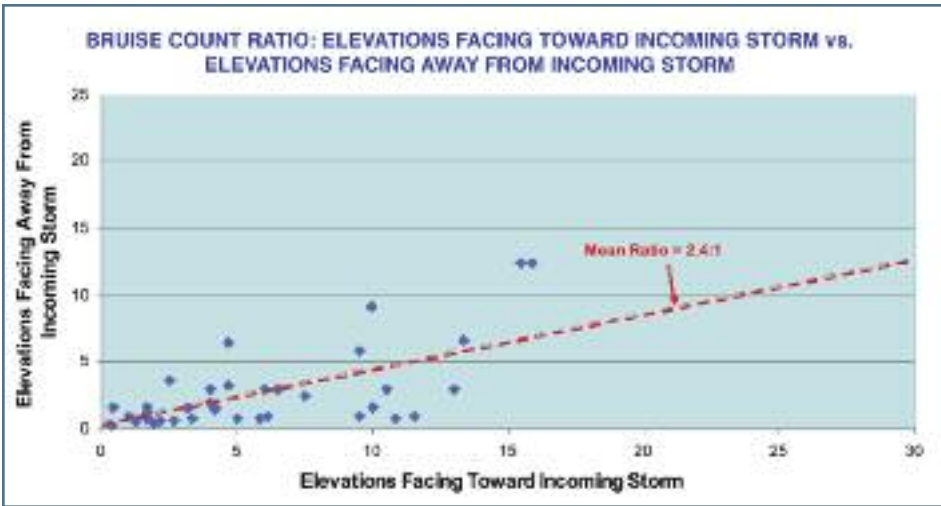


Figure 5 – Bruise count comparisons between roof elevations facing an incoming storm and roof elevations facing away from an incoming storm.

DIRECTION ROOF FACES	AVERAGE NUMBER OF BRUISES PER 100 SQ FT
Toward Incoming Storm	5.4
Away From Incoming Storm	2.3

Table 2: Hail strike bruises facing toward vs. away from incoming storm direction.

Correlation 4: Hail Damage Sustained by the Roof Elevations Perpendicular to the Incoming Storms Compared to the Roof Elevations Facing the Incoming Storms

For this correlation, the database was manipulated to include only roof elevations that were finished with asphalt shingles. This correlation focused on comparing the bruise counts received by roof elevations facing the incoming hailstorm versus the roof elevations perpendicular (see Figure 6) to the incoming hailstorm. This correlation used data gathered during the hail-damage inspections performed by EES regarding the direction each elevation faced and the direction that the storm traveled. This information was then separated into two categories: 1) elevations that were facing into the incoming storm and 2) elevations that were perpendicular to the incoming storm.

The number of hail-strike bruise counts for each test area was then manipulated to determine the number of hail-strike bruise counts per 100 sq ft. The average number of hail-strike bruises per 100 sq ft for all elevations facing into incoming storms was then calculated. This process was repeated for all roof elevations perpendicular to the incoming storm. The number of hail-strike bruises on the roof elevations facing toward the incoming storm was then compared to

the number of bruises on the roof elevations perpendicular to the incoming storm and turned into a ratio. Using data from 100 site inspections, the study found this ratio to be 2.1:1 (see Figure 7 and Table 3). Thus, a roof facing the incoming storm had bruise counts just over two times that for roof elevations perpendicular to the incoming storm.

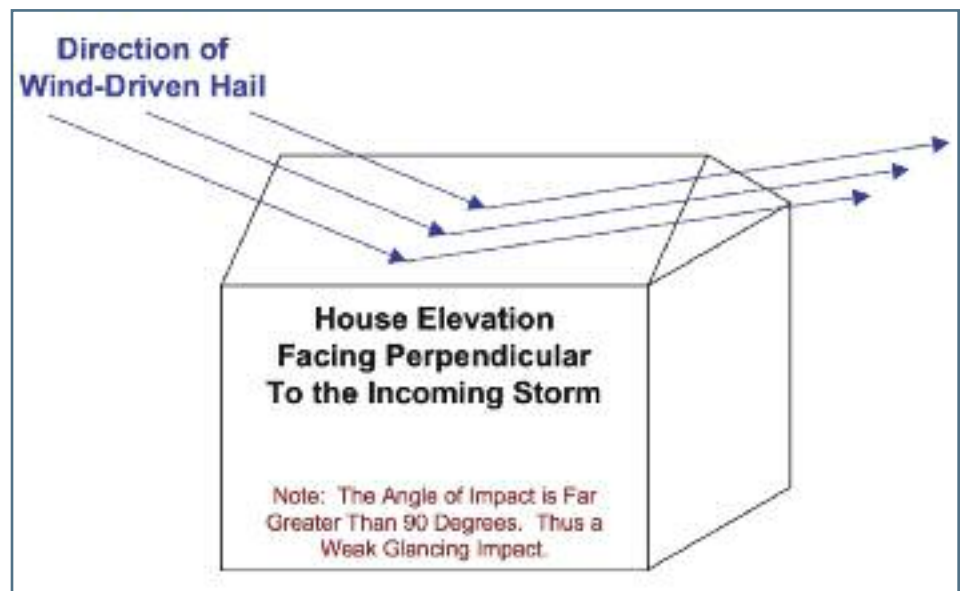


Figure 6 – Hail impact on roof elevations facing perpendicular to an incoming storm.

DISCUSSION

The number of hail-strike bruises increases at an exponential rate as the size of hail increases. Our data show that hail must reach approximately 1½ inches in order to leave a bruise count of five bruises per 100 sq ft of asphalt shingles. The level of bruises per 100 sq ft at which insurance companies consider a roof damaged sufficiently to be replaced varies but appears to range from about six to ten hail-strike bruises per 100 sq ft of roofing. A line of best fit was generated from our data points to include this information. This line was set to zero hail-strike bruises when hail was not present (by making the hail size equal to 0.0 inches in diameter) and yielded the equation $y = 0.6205^{e^{1.2369x}} - 0.6205$. Using this equation, it was calculated that the estimated diameters needed to achieve six and ten hail bruises per 100 sq ft of asphalt shingle roofing were 1.91 inches in diameter and 2.30 inches in diameter, respectively.

The consensus of previously conducted studies is that hail causes damage to asphalt roofs when hailstones measure approximately 1¼ inches to 1½ inches in diameter. However, these studies used freezer-made ice stones to reach these conclusions, and freezer-made ice stones are, in theory, denser than actual hailstones.

CONCLUSIONS

This paper was intended to correlate field data on hail-strike damage to asphalt shingles, according to the estimated size of the hail that fell versus bruise counts on roof surfaces. These correlations included

comparing the size of hail to the number of hail-strike bruises found on asphalt roofing, the pitch of the subject roof elevations compared to the number of hail-strike bruises, the correlation between the direction the roof elevation faces, the number of hail-strikes bruises on each elevation, and the direction of the incoming storm.

The study focusing on the slope of the roof compared to the number of hail-strike bruises yielded some interesting results. The roof elevations measuring above a 9-in/12-in pitch and those measuring below a 5-in/12-in pitch sustained 179% and 152% of the expected number of hail-strike bruises, respectively; while the moderately shallow roof elevations (those measuring from a 5-in/12-in to a 6-in/12-in pitch) and moderately steep roof elevations (those measuring from a 7-in/12-in to a 9-in/12-in pitch) were found to contain fewer hail-strike bruises than would be expected (56% and 74%, respectively).

Through his research, Noon⁵ came to the conclusion that hail-strike damage increases as the angle at which the hail strikes the roof nears the perpendicular. Many people assume that the less steep a roof elevation, the more susceptible to hail-strike damage the roof becomes. Noon's⁵ calculations concur with this generalization, as long as no wind is present. Koontz⁴ proved mathematically that wind-driven

hail causes an impact much greater than freefalling hail. The high bruise counts on steep roof elevations may be a product of wind-driven hail. Noon's⁵ calculations agree with this theory, in that strong winds could propel hailstones perpendicularly into steep roof elevations, causing high-impact collisions and the increased number of hail-strike bruises observed on steep roof elevations.

The direction that a roof elevation faces compared to the direction of an incoming storm contributes greatly to the number of hail-strike bruises that one could expect to find on each roof elevation. Our data show that a roof elevation facing an incoming storm contains 2.4 times more hail-strike bruises than the roof elevation facing away from an incoming storm (see *Figure 5* and *Table 2*). Also, roof elevations facing an incoming storm contain 2.1 times more hail-strike bruises than a roof elevation perpendicular to an incoming storm (see *Figure 7* and *Table 3*). These results correspond with Koontz's⁴ research regarding wind-driven hail and Noon's⁵ findings, which show that hail impacts cause the most damage when striking the roof perpendicularly (see *Figures 3* and *4*).

No well-known, large-scale, hail-size-to-roof-damage studies appear to have used actual hail inspection results to reach their conclusions; rather, these experiments

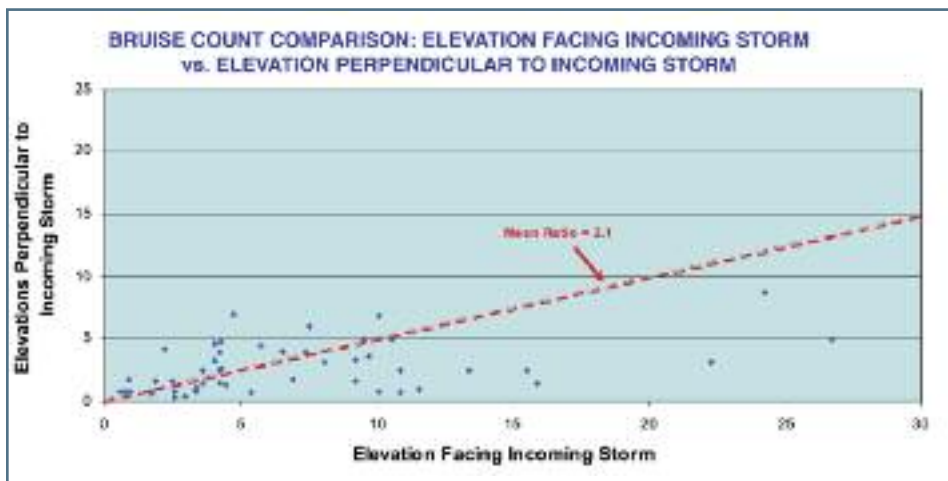


Figure 7 – Bruise count comparisons between roof elevations facing an incoming storm and roof elevations perpendicular to an incoming storm.

DIRECTION ROOF FACES	AVERAGE NUMBER OF BRUISES PER 100 SQ FT
Toward Incoming Storm	6.2
Perpendicular to Incoming Storm	3.0

Table 3: Hail-strike bruises facing vs. perpendicular to storm.

BUILDING ENVELOPE KNOWLEDGE ASSESSMENT

Test your knowledge of building envelope consulting with the following questions developed by Donald E. Bush, Sr., RRC, FRCI, PE, chairman of RCI's RRC Examination Development Subcommittee.

1. Curtain walls can be classified by their method of fabrication and installation into the following general categories: stick systems and unitized or modular systems. What is a unitized system?
2. What is a stick system?
3. Water can enter the exterior wall system by means of five different forces. What are these forces?
4. What are the three rain-screen systems available for curtain walls?
5. Which rain-screen system normally provides the highest levels of resistance to air and water infiltration?
6. Thermal performance of opaque areas of the curtain wall is a function of what two components?

Answers on page 10


BUILDING ENVELOPE KNOWLEDGE ASSESSMENT

Answers to questions from page 9:

1. The unitized system is composed of large units that are assembled and glazed in the factory, shipped to the site, and erected on the building.
2. The curtain wall frame (mullions) and glass or opaque panels are installed and connected together piece by piece on site.
3. Gravity, kinetic energy, air pressure difference, surface tension, and capillary action.
4. Face-sealed, water-managed, and pressure-equalized.
5. Pressure-equalized.
6. Insulation and air/vapor barriers.

REFERENCE:

Whole Building Design Guide (WBDG)

replicated hailstones by using freezer-made ice stones. Freezer-made ice stones are, in theory, denser than actual hailstones, due to the process that creates hail. Natural hailstones are created by continually contacting super-cooled water vapor. The moisture either instantly freezes or turns into a bubble. The bubbles in this process lock air into the hailstone, creating a less dense particle than the freezer-made ice stones. Also, these studies launched the ice stones at their maximum free-fall velocities at a perpendicular angle, thus creating the most devastating impact possible. Our data found that hail caused elevated hail-strike bruise counts to asphalt shingles when hail reached 1¾ inches to 2 inches in diameter. This slight size increase over previous studies may be explained by taking into account the difference in density between freezer-made ice stones and actual hail and the perpendicular angle that the freezer-made ice stones were launched at the test panels. 

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ASCE ISSUES INFRASTRUCTURE REPORT CARD

The American Society of Civil Engineers has issued its third report card on the state of the nation's infrastructure, and the results are not pretty. Only one category that of the electrical power grid has improved, albeit from a D to a D+. The poor status reported in 2001 and 2005 is unchanged, and the estimate to correct the gap is now estimated at \$2.2 trillion. Current grades follow:

SECTOR	2009 GRADE	SECTOR	2009 GRADE
Aviation	D	Public parks & recreation	C-
Bridges	C	Rail	C-
Dams	D	Roads	D-
Drinking water	D-	Schools	D
Energy (national power grid)	D+	Solid waste	C+
Hazardous waste	D	Transit	D
Inland waterways	D-	Wastewater	D-
Levees	D-		