# INFLUENCE OF NAIL LOCATIONS ON WIND RESISTANCE OF UNSEALED ASPHALT SHINGLES

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Self-sealing asphalt shingles that are unsealed are vulnerable to damage when exposed to strong winds. The potential for damage is related to a number of factors, including fastener locations. A consortium of the National Roofing Contractors Association (NRCA) and four manufacturers sponsored research on wind performance of unsealed shingles in a wind tunnel to establish a correlation between shingle damage and a matrix of factors.

This paper presents an analysis of the relationship between fastener location and shingle damage, based on data collected during the wind tunnel testing. It also reports on manufacturers' recommendations regarding fastener location variations. Conclusions and recommendations based on the data analysis are provided.

Currently, there are no industry-accepted criteria on allowable variations for the location of fasteners used to attach asphalt shingles. The paper's recommendations can be used to establish allowable fastener location variations. The recommendations also can be used to provide direction as to when corrective action needs to be taken for fasteners that deviate from target locations.

## KEYWORDS

Asphalt Shingles, Blow-off, Fastener Location, Fastener Tolerances, Nail Location, Nail Tolerances, Steep-slope Roofing, Unsealed Asphalt Shingles, Wind Performance.

## INTRODUCTION

When self-sealing shingles experience strong winds before sealant activation, the shingles are vulnerable to damage. The potential for damage (such as tearing near fasteners, fastener pull-through,[1] tab cracking or tab tearing) is related to a number of factors, such as the location of fasteners, shingle fastener's pull-through resistance,[2] shingle pliability, tear strength and overall product strength.

In 1998, the consortium of NRCA and asphalt shingle manufacturers sponsored research on wind performance of unsealed asphalt shingles. The work was conducted in a wind tunnel at Colorado State University (CSU). The purpose of the project was to establish a correlation between unsealed shingle damage and a small matrix of factors, as reported in Reference 1.

[1] *The term "fastener pull-through" refers to a shingle pulling over a fastener head.*

[2] *The term "shingle fastener's pull-through resistance" refers to a shingle's ability to avoid pulling over a fastener head.*

After the test specimens were tested in the wind tunnel, the authors recorded the presence of shingle damage near the fasteners. The fastener locations also were recorded. Most of the fasteners were placed in the general locations specified in the *ARMA* (Asphalt Roofing Manufacturers Association) *Residential Asphalt Roofing Manual* [2]. However, even though applied by an experienced mechanic, most of the fasteners were unintentionally offset slightly from the published criteria. Currently, there are no industry-accepted criteria on allowable variations for the location of fasteners.

This paper presents an analysis of the data on wind-induced shingle damage as a function of fastener location. These data can be used to establish allowable fastener location variations. Data on acceptable variance from target fastener locations can be used by the ARMA/NRCA Asphalt Shingle QC Document Task Force and others in providing direction as to when corrective action needs to be taken when fasteners deviate from target locations.

Note: In addition to providing wind resistance, fasteners also play an important role related to shingle expansion and contraction. The influence of fastener placement on thermal movement was not part of the research. However, if fasteners are placed in accordance with the recommendations given in this paper, they should provide satisfactory shingle attachment with respect to expansion and contraction.

## ATTACHMENT ORIGIN

The first asphalt shingles were produced in 1901; however, they did not come into general use until about 1911 [3]. The birth of the asphalt shingle market is credited to a 1916 booklet sponsored by the National Board of Fire Underwriters (NBFU), which called for the elimination of wood shingles [4]. The NBFU position was in response to a large number of building fires during the late 19th and early 20th centuries, which were in large part attributed to wood shingles' susceptibility to ignition from flying brands.

A 1925 document was the earliest description of attachment of asphalt strip shingles discovered by the authors [5]. It illustrates a four-tab shingle, with nails located ½ inches (12.7 mm) above each cutout, and a nail near each end of the shingle. Three-quarter-inch- (19-mm-) long galvanized clout nails were specified.

A 1941 document was the earliest description of attachment of three-tab asphalt shingles discovered by the authors [3]. It notes that 11- or 12-gauge galvanized nails with a ⅜-inch (9.5-mm) minimum diameter head usually are recommended. For typical conditions, it shows four nails per shingle. "For severe conditions, such as prevailing high winds," this document states, "the shingles will be fastened more securely" if six nails per shingle are used. The drawings showing the four and six nail applications do not give dimensions for the fastener locations, but the fasteners are shown in the same locations as illustrated in the *ARMA Residential Asphalt Roofing Manual* and *The NRCA Roofing and Waterproofing Manual* [6].

The earliest document discovered by the authors that gives dimensions for the location of fasteners for three-tab shingles is from 1947 [7]. It specifies six nails per shingle, located 5⅝ inches (143 mm) above the exposed edge of the tab, with the end fasteners located 1 inch (25 mm) from each end. A nail is specified at 1½ inches (38 mm) on either side of the cutout's center line. It specifies galvanized roofing nails with a ⅜-inch (9.5-mm) minimum diameter head.

By 1958, the 1947 attachment recommendations had changed slightly [8]. A minimum of four nails rather than six were recommended, with the nails centered over the cutouts. The distance above the exposed edge of the tab (5⅝ inch [143 mm]) and the edge distance of the end fasteners remained the same. Galvanized roofing nails with a ⅜-inch (9.5-mm) minimum head diameter were still specified; however, it was additionally stipulated that the nails be 11 or 12 gauge.

Except for high-wind areas, current nailing recommendations in the *ARMA Residential Asphalt Roofing Manual* are identical to the 1958 attachment recommendations. For high-wind areas, ARMA's recommendations are nearly identical to the 1947 attachment recommendations, with the primary difference being that in lieu of fastener placement at 1½ inches (38 mm) on either side of the cutout, 1 inch on either side of the cutout is now recommended by ARMA. *The ARMA Residential Asphalt Roofing Manual* also now provides location criteria for laminated shingles.

*The NRCA Roofing and Waterproofing Manual* provides some guidance on nail locations for four- and six-nail patterns. End nails are prescribed as "approximately" 1 inch (25 mm) from each end. At the cutouts, the nails are shown centered over the cutouts for four-nail patterns and on either side of the cutouts for six-nail patterns (the manufacturer's instructions are referenced for specific placement locations). The nails are to be located "slightly" above the cutouts, with the manufacturer's instructions referenced for specific placement locations. Location criteria for laminated shingles are not provided.

## CSU RESEARCH

Reference 1 describes how products were selected for the research, and what some of the physical properties of the selected products, test conditions and result are. The following is a synopsis of key items related to this paper.

Type of products: Two organic-reinforced three-tab, two fiberglass-reinforced three-tab and two fiberglass-reinforced laminated shingles were selected. Based on lab data, it was postulated that one product in each of these categories would be a relatively good performer and the other would be a relatively poor performer. One SBS-modified three-tab shingle also was included.

Application: The shingles were installed by a roofing contractor who is a member of NRCA. The mechanic was experienced in the correct application of asphalt shingles. The shingles were applied over plywood decks that were 4 feet (1219 mm) wide and 3 feet (914mm) long, as shown in Figure 1. Most of the shingles were attached with four nails, but six nails per shingle were used on some decks. On some decks, the nails were intentionally located incorrectly (i.e., they were placed approximately 1½ inches [38 mm] above the nail line). However, for the other decks, the contractor was instructed as follows:

"Fasteners need to be located quite close to the idealized locations. Measuring is not required, but attention needs to be given to installing the fasteners close to the specified locations."

The nails were hand-applied 11-gauge electroplated roofing nails with ⅜-inch (9.5-mm) diameter heads. For the three-tab shingles, the nails were to be placed ⅝ inch (16 mm) above the cutout. The end nails were to be placed 1 inch (25 mm) from the end of the shingle. For four-nail applications, the nails were to be centered above the cutouts. For six-nail applications, the nails were to be placed 1 inch (25 mm) on either side of the cutout center line.

For the laminated shingles, the nails were to be placed on the nailing line. The end nails were to be 1 inch from the end of the shingle. The other nails were to be located at the one-third points.

On a few decks, the shingles were attached with staples for comparison purposes. However, because staple attachment is not addressed in either the *ARMA Residential Asphalt Roofing Manual* or *The NRCA Roofing and Waterproofing Manual*, staple attachment was not assessed for this paper.

Test conditions: Each deck was subjected to wind speeds of 50, 60 and 70 mph (22, 27 and 31 m/s). Most decks were tested for five minutes at each speed; however, a few were tested for 10 minutes at each speed (these were designated as "long duration"). A portion of the decks were tested at approximately 70°F (21°C), and the remainder were

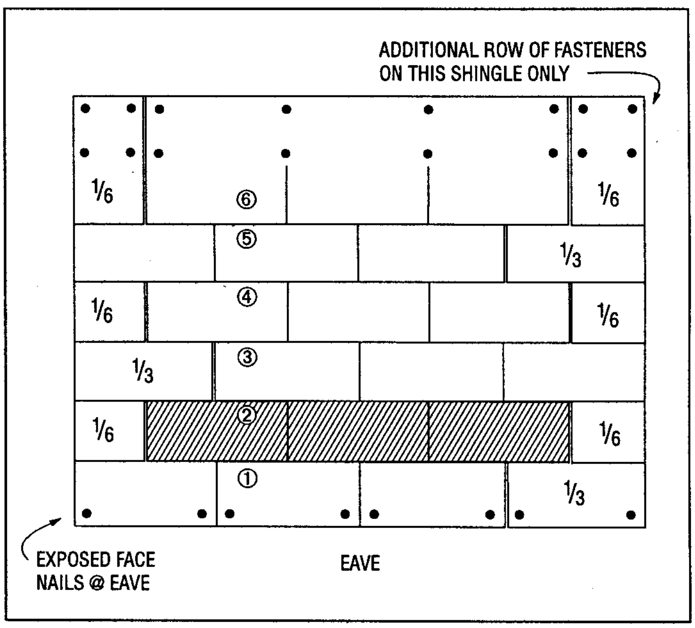


*Figure 1. Test deck layout. Note: Fastener data analysis of this paper was limited to row 2 (shaded area).*

tested at approximately 35°F (2°C). A total of 121 decks were tested.

Replicates: For each test condition, four replicate decks typically were tested (i.e., four essentially identically constructed and tested decks). However, in a few cases, eight replicates were tested.

Damage index: After completion of the testing, the test deck carefully was inspected visually for damage and given a damage index by a CSU researcher. The index was determined by assigning points for various types of damage, as described in Reference 1.

## FASTENER LOCATION DATA

Of the 121 tested decks, 93 decks were potential candidates for this paper. The other 28 decks were not applicable (i.e., 13 of these decks were attached with staples, twelve decks had the nails intentionally placed very high [i.e., approximately 1½ inches (38 mm) above the nailing line], and three decks were tested in the sealed condition). For the 93 candidate decks to be considered for evaluation, the authors required that fastener location data be available for at least three replicates.

The inspections that were made following the first several runs did not include careful analyses of the nail locations because it was believed that the nails were located quite close to their specified locations. However, it was soon realized that some of the nails were further from their specified locations than desired. Afterward, the nail locations were measured.[3]

The authors ended up with 50 suitable decks for this evaluation. Twenty-two of these decks were tested at 70°F (21°C) and 28 at 35°F (2°C). Forty-seven of the decks were attached with four nails per shingle, and three decks were attached with six nails per shingle. A summary of the 50-deck data set is provided in Tables 1-3.

Most of the decks that experienced damage had damage in rows two and six (see Figure 1).[4] Little or no damage typically occurred in rows 3, 4 and 5 (row 2 typically lifted and shielded rows 3 and 5). The top row (row six, or row five in the case of the metric shingles), was an atypical condition because the top row was not restrained by overlying shingles. Therefore, this evaluation is based only on nail locations in the full shingle on row two (Figure 1). This resulted in an evaluation of 198 nail locations.

The Appendix contains work sheets on each of the 50 decks. The work sheets give the nail locations and the damage (or lack thereof) in the vicinity of the nails. The damage index for the deck is also given. Typically, row 6 contributed the highest percentage of the damage index, followed by row 2.

| Product Designation | Product Type |
|---|---|
| A2 | Organic three-tab |
| B1 | Fiberglass three-tab |
| B2 | Fiberglass three-tab |
| C1 | SBS three-tab |
| D2 | Fiberglass laminated |

*Table 1. Product Designations and Types. Note: See Table 2 for physical properties.*

## FASTENER DATA ANALYSIS

Fifteen of the 198 nails were located as specified (8 percent). Forty-one (including the previous 15) of the 198 nails were located within 1/16 inch (1.6 mm) of the specified location (21 percent). Eight-six (including the previous 41) of the 198 nails were located within ⅛ inch (3.2 mm) of the specified location (43 percent). Of the remaining 112 nails (57 percent) all were between ⅛ inch (3.2 mm) and ½ inch (12.7 mm) from the specified location, except for one which was offset by ⅞ inch (22.2 mm).

Of the 112 nails, 13 (7 percent) of them were offset (½ inch [12.7 mm]). Eleven of these were end nails. The other 2 nails were at cutouts in a shingle with six nails. Nine of the end nails were ½ inch (12.7 mm) from the end, and one nail was 1½ inch (38 mm) from the end.

Although the greatest distance from the specified location occurred with end fasteners, tears only occurred at four end fasteners (decks B1A3, B1G3, B1G4 [tab blew off] and B2C7). A severe crack also occurred at one end fastener (B1A1). Hence, while only 5 percent of the shingles had damage at their ends, 68 percent of the end nails were greater than ⅛ inch (3.2 mm) from their specified location.[5]

Within each replicate set, the row 2 shingle damage, damage index and nail locations were examined for each run. The A2 (good performing organic) and C1 (SBS-modified bitumen) replicates did not experience any damage in row 2. Damage occurred in at least one run in all the other replicate sets. In sets B1A and B1C, there was considerable variation in the damage indices (42-114 and 32-166). However, with all of the data sets, none of the variation in damage appeared to be related to nail locations, as illustrated by the following examples:

B1A3 had a crack at one cutout, a tear at the other cutout and tear at the end. The nails at the cutout were 1/16 inch (1.6 mm) above the specified location and both end nails were within ⅛ inch (3.2 mm) of the specified location. This run was the only one in the replicate set that had all four nails within ⅛ inch (3.2 mm) of the specified locations. However, it had more damage in row 2 than any of the other three runs.

B1C6 had a V-shaped tear at each cutout. The nails at both cutouts were 1/16 inch (1.6 mm) below the specified location. This is in contrast to B1A3, where the nails at the cutouts were 1/16 inch (1.6 mm) high. B1C was a normal duration run, whereas B1A was a long duration run.

B1C3, which was in the same set as B1C6, also had a V-shaped tear at a cutout. The nail at this location was 5/16 inch (7.9 mm) below the specified location. As with B1C6, the nails at both cutouts at B1C7 were 1/16 inch (1.6 mm) below the specified location. However, rather than small V-shaped tears, B1C7 had large vertical tears extending up from the top of each cutout.

In this replicate set, in different runs, shingles with identical nail placement had substantially different damage.

[3] *Measurements were made to the center of the nail head, and they were made to the nearest 1/16 inch (1.6 mm).*

[4] *For the metric shingles (i.e., C1 and D2), there were only five rows of shingles.*

[5] *The location was not determined for five end nails. There was no shingle damage in the vicinity of these fasteners.*

Conversely, in other runs, shingles had virtually identical damage, but nail locations differed by as much as ¼ inch (6.4 mm).

B1E3 had two small tears at the cutouts, whereas B1E1 had large tears at the cutouts. Although the damage was quite different, the nails above the cutouts in each of these runs were almost identically located. Each run had one nail that was ⅜ inch (9.5 mm) below the specified location. B1E2 had one nail that was ⅛ inch (3.2 mm) below the specified location, yet it, too, had a large tear at the cutout.

B1G3, which was in the same replicate set as the B1E runs, had one nail at a cutout that was 1/16 inch (1.6 mm) below the specified location. At the other cutout, the nail was ⅛ inch (3.2 mm) below the specified location. Although these nails were more accurately located than those at B1E1, B1E2 and B1E3, the tab was blown off between the cutouts and there were large tears extending from each cutout of B1G3.

B2C5 had one nail located above a cutout as specified. At the other cutout, the nail was ⅛ inch (3.2 mm) above the specified location. A short tear developed above the cutout with the correctly located fastener, and a deep crack developed above the other cutout. At B2C8, nails at both cutouts were the correct distances above the cutouts, but each was horizontally offset by ⅛ inch (3.2 mm).[6] Short tears developed above each cutout.

The B2D and B2G runs (which were replicates) had tears from or above 10 of the cutouts. Seven of the nails near the tears were within ⅛ inch (3.2 mm) of the specified location, and one of these (B2G3) was located exactly as specified. In contrast, the nail at one cutout (B2D3) was 5/16 inch (7.9 mm) below the specified location, but the shingle was not damaged.

## MANUFACTURERS' RECOMMENDATIONS

Fifteen asphalt shingle manufacturers were contacted to obtain their position on nail location variations. In some instances, two different company representatives were contacted, and each gave a different response. Most of the manufacturers advised that they do not have written guidelines, but they offered an oral response to the inquiry. Responses are summarized as follows:[7]

Two manufacturers do not offer tolerances. One of these advised that out-of-place nails are not used as an excuse for rejecting complaints, but if out-of-place nails caused or contributed to a problem, the complaint would be rejected.

Four manufacturers stated that nails are allowed in the sealant line, but not in the sealant itself.

One manufacturer allows nails in the sealant itself.

One manufacturer requires the nail to be between the cutout and sealant strip.

One manufacturer allows a ⅛ inch to ¼ inch (3.2 to 6.4 mm) variation.

One manufacturer permits a 3/16 inch (4.8 mm) variation. However, another representative provided guidance that was quite different: A fastener could not be more than 1⅛ inch (28.6 mm) above or ⅛ inch (3.2 mm) below the specified location. No more than one fastener in any shingle can be placed into or above the sealant strip. At least 90 percent of the fasteners are required to be within ⅜ inch (9.5 mm) of the specified location, and no more than 10 percent of the fasteners shall be in or above the sealant strip within 5 feet (1524 mm) of an affected shingle.

One manufacturer advised that the nail head had to touch the nail line.

One manufacturer does not allow the nail to be exposed. It allows the nail to be placed within approximately ¼ inch (6.4 mm) above or below the nailing line. Similarly, another manufacturer recommended the fastener be placed within ¼ inch (6.4 mm) of the nail line.

Two manufacturers stated that the nail must penetrate both pieces of laminated shingles. In addition, one stated that the nail head could not be exposed.

One manufacturer stated that ⅛ inch (3.2 mm) variation was allowed for laminated shingles.

One manufacturer follows guidance in a document that ARMA developed for the manufactured housing industry. The document is not publicly available.

## CONCLUSIONS

- In the analyzed data set, only 8 percent of the nails were located exactly as specified. However, the authors judged the fastener placement on the test decks to be more accurate than what is typically found on most projects.

  It is unrealistic to expect fasteners to be installed exactly in the specified locations. Some variation in fastener location is recognized by 13 of the 15 manufacturers that were contacted.
- There is a need for a published industry consensus on acceptable fastener location variations. Without an industry consensus, roofing contractors who apply asphalt shingles are in jeopardy of having jobs rejected because of noncompliance with fastener location criteria.

  This is a particularly acute issue for those contractors installing shingles produced by manufacturers that do not permit a tolerance. For example, one manufacturer stated that if out-of-place nails caused or contributed to a problem, the complaint would be rejected. The difficulty with this position is determining whether a fastener did, in fact, contribute to the problem.

  Several of the examples discussed under "Fastener Data Analysis" illustrate tears near slightly offset fasteners. It could be construed that the offset contributed to the tearing. However, other fasteners in the replicate set were exactly located, yet they, too, experienced tearing. Additionally, other fasteners were further offset, yet tearing did not occur. Hence, the data truly do not support the conclusion that relatively small offsets contribute to tearing.
- The guidance offered by manufacturers on acceptable fastener location variation does not appear to be based on research, nor is it realistic. Allowable variations generally ranged from ⅛ inch (1.6 mm) to ¼ inch (3.2 mm), which is not reflective of installers' fastener placement capability.

[6] *In this paper, "horizontal offset" refers to a fastener that is located to the left or right of the specified fastener location, along a line parallel to the long dimension of the shingle.*

[7] *More than 15 responses are listed because some manufacturers have different criteria for three-tab and laminated shingles.*

- Damage variability in the analyzed data set was primarily related to product variability. As shown in Table 2, there were huge variations in physical properties of the shingles tested. In addition to the large variation from product-to-product, there also was considerable shingle-to-shingle variation [1].

  In the analyzed data set, ½ inch (12.7 mm) was the maximum horizontal offset from the specified locations. For the vertical offsets, the maximum offsets above and below the specified locations were ⅞ inch (22.2 mm) and ½ inch (12.7 mm).[8] However, there was no instance in which shingle damage appeared to be related to fastener offset.

  While relatively minor variations in fastener placement appear to be inconsequential, fasteners that are substantially offset can significantly contribute to wind-related damage when the tabs are unsealed. This was illustrated by intentionally placing nails approximately 1½ inches (38 mm) above the nailing line on some of the laminated shingle decks. In those cases, the nails only penetrated a single thickness of material. The damage index significantly increased for the decks that were intentionally nailed high, versus those that were nailed at or near the specified locations [1].

  The influence of substantially offset fasteners on the wind performance of sealed shingles is not documented in the literature. However, as illustrated by Photo 1, it is likely that relatively large offsets are not problematic as long as the tabs remain sealed.

- In the analyzed data set of three-tab shingles, there were very few instances of damage near the end fasteners, though many of the end fasteners were offset by as much as ½ inch (12.7 mm). This suggests that influence of fastener location is less important at the end, compared with the cutouts.[9]
- There were insufficient data from this project to draw conclusions concerning offset influences in six fastener applications (i.e., two fasteners near each cutout). There also were insufficient data to draw conclusions about minor offset influences with laminated shingles.

  Note: The nail line on one of the laminated shingles that was tested was very close to the line where the two pieces of material were laminated. Even though the nails were placed on the nail line, there was insufficient edge distance between the nail shank and edge of the double thickness of material to develop full fastener resistance. This was a manufacturing problem [1].
- Most manufacturers are adamant about the fastener not being located in the sealant strip.[10] However, with

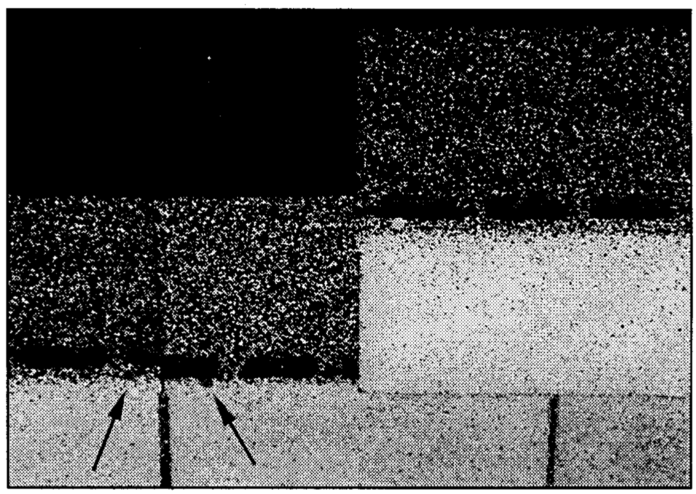

***Photo 2.*** *This roof is under construction. The end nail at the lower left corner was located as specified. However, the end fastener at the adjacent shingle was placed lower than specified in order to avoid placing the nail in the sealant (the sealant strip is lower on this shingle).*

[8] *In this paper, "vertical offset" refers to a fastener that is located above or below the specified fastener location, along a line perpendicular to the long dimension of the shingle.*

[9] *The data set only includes three laminated shingle test decks. Locations of end fasteners were not determined on one of these decks. Hence, there are insufficient data to extend this conclusion to laminated shingles.*

[10] *The concern with fasteners located in the sealant strip typically is related to the decrease in the sealant surface area because of interference of the fastener head. Also, if the fastener head is not flush with the shingle surface, the overlying shingle will be tented, thereby causing an even larger area to be unbonded.*

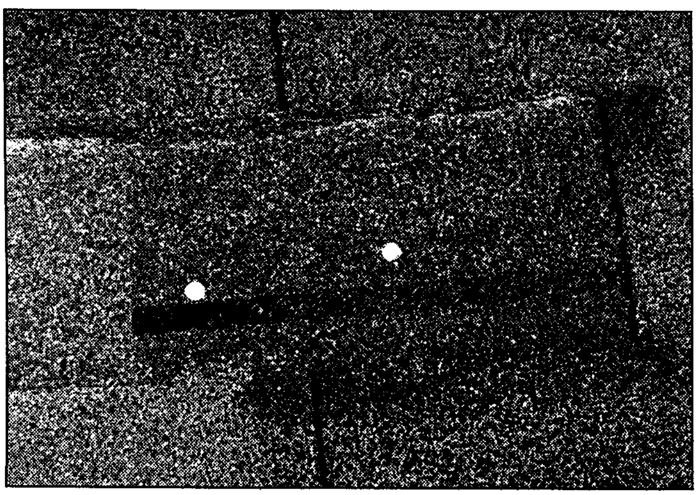

***Photo 1.*** *This roof lost a few tabs during a storm. These fasteners were substantially offset from the specified locations. However, tab blow-off was related to inadequate bonding of the sealant, rather than fastener location.*

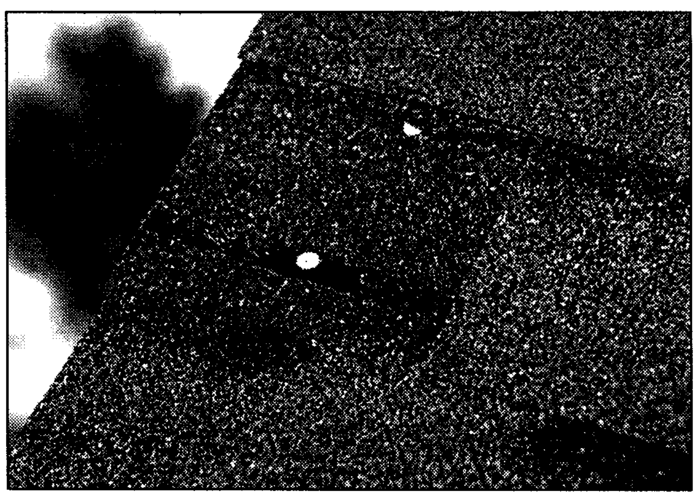

***Photo 3.*** *This roof lost a rake tab during a storm. Because the shingle extended past the edge of the deck, the nail was located inward of the typical location for end fasteners.*

product B1, in some instances, the nail head engaged the sealant even though the nail was located ⅛ inch (3.2 mm) below the specified location (see B1E2 in the Appendix). Photo 2 (from a job under construction) also shows sealant strip location variability.

- Rake nails typically are located substantially more than 1 inch (25 mm) from the end of the shingle (Photo 3). The authors did not find any criteria regarding location of rake fasteners. Because of the rake overhang and the high wind uplift loads along the rake, guidance for rake fastening location is needed.
- Where there is a target, such as a nailing line or center line of a cutout, the data set shows that there is improved fastener location accuracy. When a nailing line is provided, it should be readily apparent. On one of the laminated products, the nailing line was difficult to see.

## RECOMMENDATIONS

Further wind-tunnel studies should be conducted on unsealed shingles with the specific purpose of determining the size and shape of permissible fastener location zones. This information should then be the basis for determining when an additional fastener should be installed because of placement beyond the zone. The corrective-action criteria should be incorporated into the ARMA/NRCA quality-control document (currently under development).

Until further research is conducted on fastener location influences, the following are recommended:

- Horizontal offset: ½ inch (12.7 mm) on either side of the specified location should be acceptable for three-tab shingles. For field fasteners at laminated shingles, 2 inches (52 mm) on either side of the specified location should be acceptable.[11] However, with laminated shingles, consideration needs to be given to the shingle side lap. A side lap should be selected that will permit fasteners to be placed 2 inches (52 mm) on either side of the specified location, while keeping the fasteners away from the underlying shingle butt joints to avoid leakage problems.

  If the nailing line on laminated shingles has marks for the field fasteners, the ½ inch (12.7 mm) variation should apply (if the nailing line is not marked, it is difficult for the applicator to accurately position the field fasteners along the line).

  If the fastener is offset more than as previously noted, an additional fastener should be installed in the specified location.
- Vertical offset, below the specified location: Fastener heads should not be so low that they are visible after the overlying shingle is installed. If they are visible, the overlying shingle and shingle below should be removed and new shingles installed.
- Vertical offset, above the specified location: If the fastener is more than ½ inches (25 mm) above the specified location, an additional fastener should be installed in the specified location.

Note: Manufacturers should anticipate that some fastener heads will be placed in the sealant area (this sometimes occurs even when fasteners are located as specified). The bond strength of the sealant or amount of sealant surface area should be great enough to provide ample tab bonding even though there is occasional occurrence of fastener heads in the sealant.

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## APPENDIX

The following work sheets provide row 2 data for the replicates shown on Table 3. The replicate ID, test temperature, run number, damage index, nail locations and shingle damage are noted.

Nail location nomenclature:

U = the distance the nail center line is up from the top of the cutout (or from the nail line in the case of the laminated shingles).

O = the distance the nail is over from the center line of the cutout or end of the shingle.

* = nail that was located as specified.

** = nail that was within 1/16 inch (1.6 mm) of the specified location.

*** = nail that was within ⅛ inch (3.2 mm) of the specified location.

[11] *Because of insufficient test data, this recommendation is based on the authors' judgment.*

| | A2 | B1 | B2 | C1 | D2 |
|---|---|---|---|---|---|
| Weight (pounds/square) | 243 | 251 | 245 | 236 | 348 |
| Felt weight (grams/m²) | 560 | 100 | 108 | 106 | 102 |
| Tear strength, MD (grams) | 3153 | 1678 | 1709 | 1933 | 2137 |
| Tear strength, XD (grams) | 2828 | 1303 | 1992 | 2543 | 2095 |
| Nail pull-through at room temperature, lbf | 35 | 20 | 27 | 24 | 33/64 |
| Nail pull-through at 30°F (-1°C) | 70 | 33 | 38 | 44 | 48/97 |

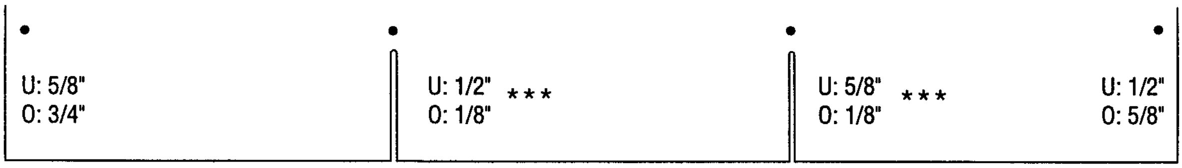
Note: The first value of the nail pull-through data for D2 is for an area of shingle with a single thickness. The second value is for an area of double thickness.

*Table 2. Summary of material characterization*

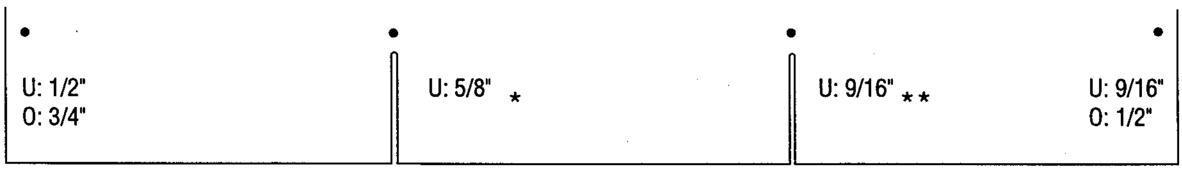
| Replicate ID | Number of Decks in Set | Temperature | Remarks |
|---|---|---|---|
| A2B | 3 | 70°F (21°C) | |
| A2C | 4 | 35°F (2°C) | |
| B1A | 4 | 70°F (21°C) | Long Duration |
| B1C | 6 | 70°F (21°C) | |
| B1E/G | 7 | 35°F (2°C) | |
| B1F | 3 | 35°F (2°C) | Six Nails per Shingle |
| B2C | 6 | 70°F (21°C) | |
| B2D/G | 8 | 35°F (2°C) | |
| B2H | 3 | 35°F (2°C) | Long Duration |
| C1B | 3 | 35°F (2°C) | |
| D2A | 3 | 70°F (21°C) | |

Note: The first letter and number under the Replicate ID indicates the product designation. The next letter indicates the run number of that product series of tests. Two letters after the number (e.g., B1E and B1G) indicates that those two runs were replicates.

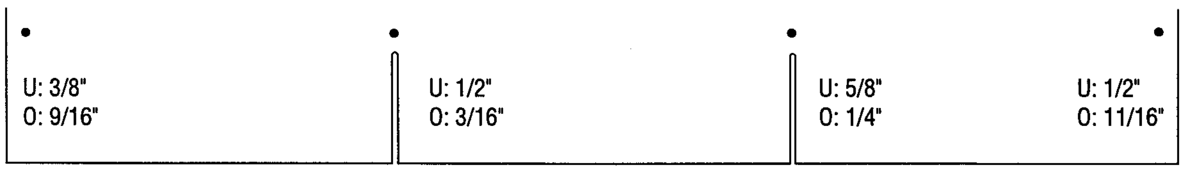
*Table 3. Summary of 50-deck data set*



A2 B1 70° RUN 65 DAMAGE INDEX: 4

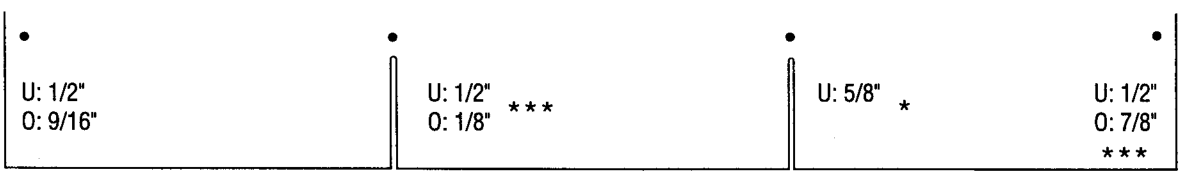


A2 B3 70° RUN 67 DAMAGE INDEX: 8

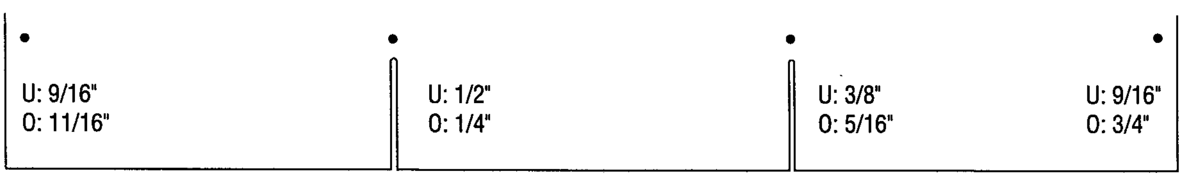


A2 B4 70° RUN 68 DAMAGE INDEX: 0

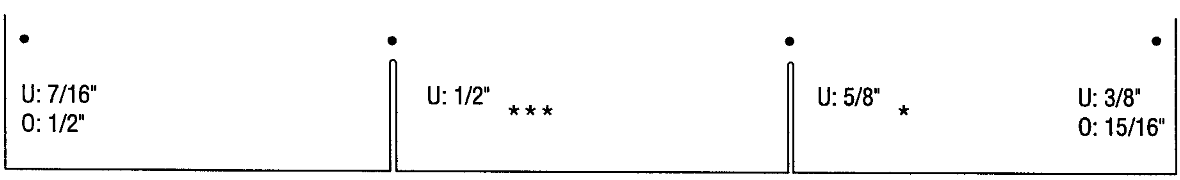
A2 C1 35° RUN 69 DAMAGE INDEX: 0



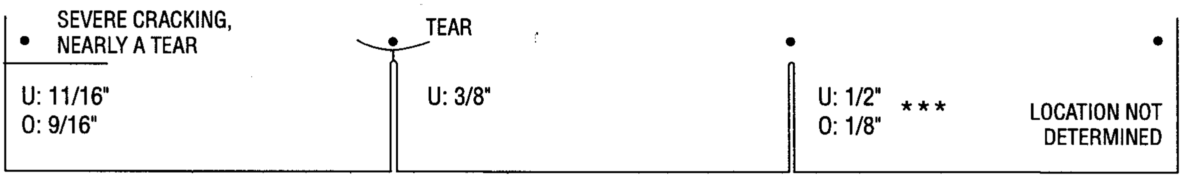
A2 C2 35° RUN 74 DAMAGE INDEX: 0



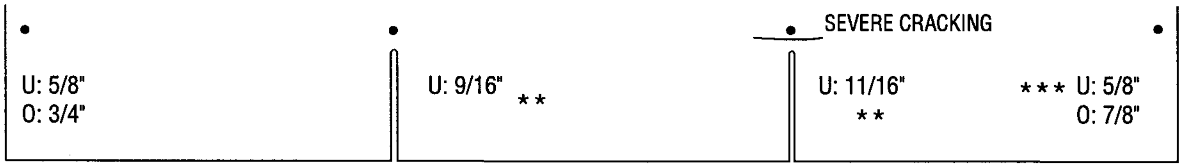
A2 C3 35° RUN 78 DAMAGE INDEX: 0



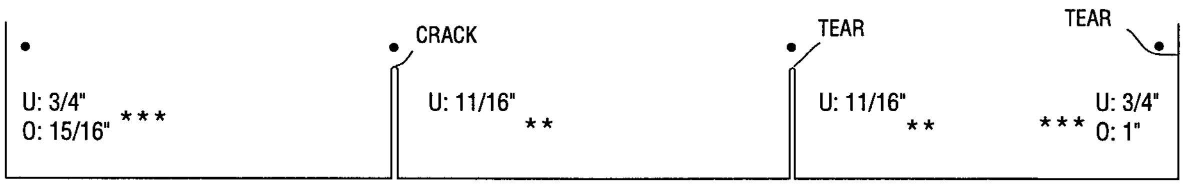
A2 C4 35° RUN 82 DAMAGE INDEX: 0



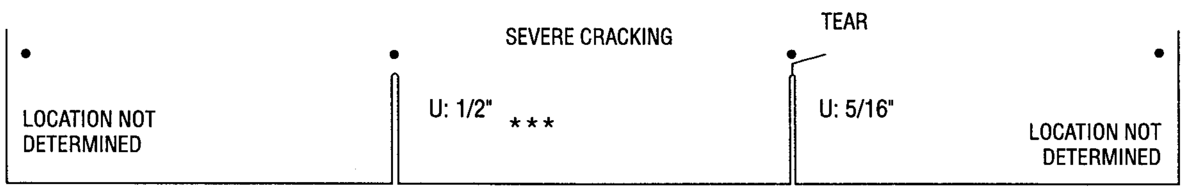

B1 A1 70° RUN 61 DAMAGE INDEX: 114 LONG DURATION




B1 A2 70° RUN 62 DAMAGE INDEX: 42 LONG DURATION




B1 A3 70° RUN 63 DAMAGE INDEX: 62 LONG DURATION




B1 A4 70° RUN 64 DAMAGE INDEX: 68 LONG DURATION

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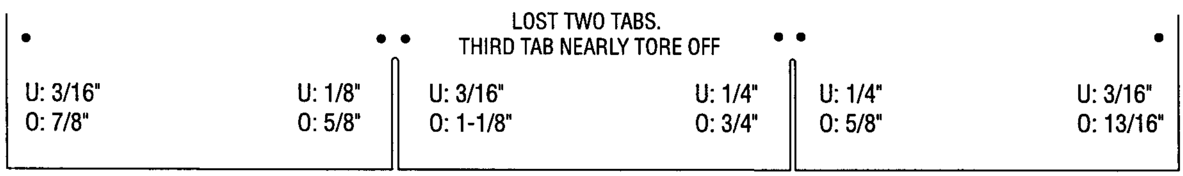
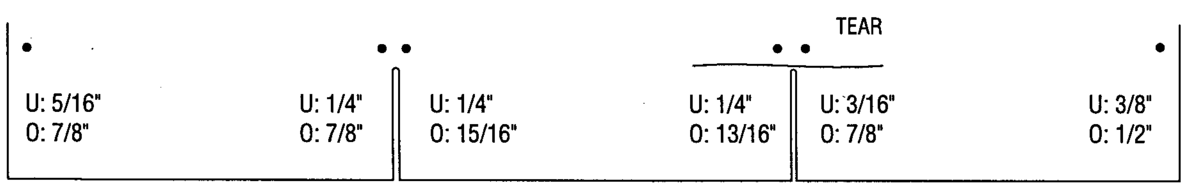
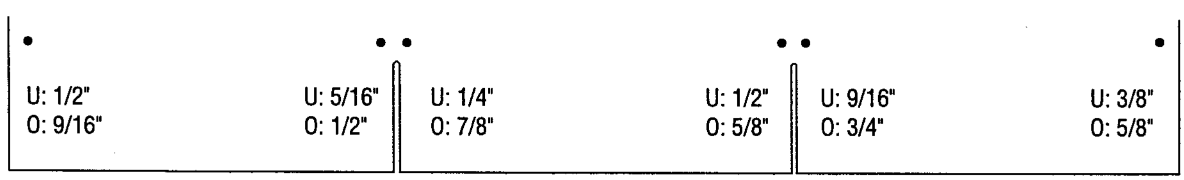


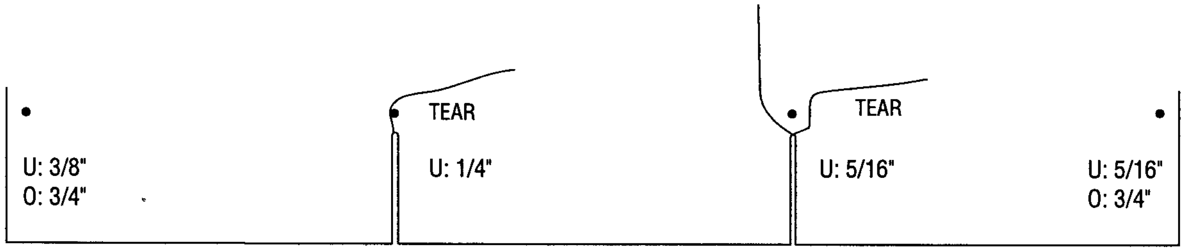

B1 F2 35° RUN 104 DAMAGE INDEX: 72



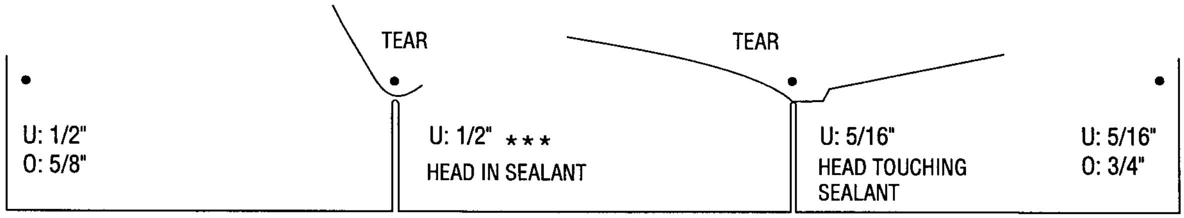

B1 F3 35° RUN 109 DAMAGE INDEX: 50




B1 F4 35° RUN 113 DAMAGE INDEX: 18




B1 E1 35° RUN 79 DAMAGE INDEX: 52




B1 E2 35° RUN 70 DAMAGE INDEX: 48


B1 E3 35° RUN 85 DAMAGE INDEX: 46

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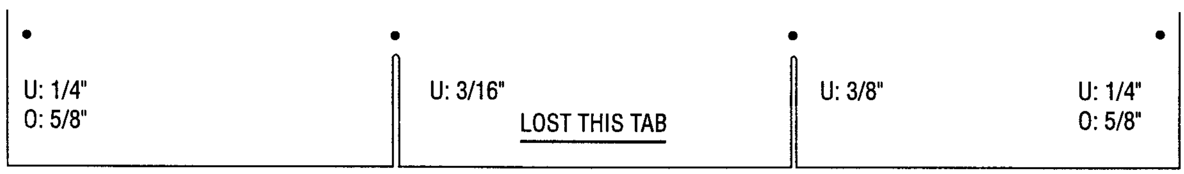
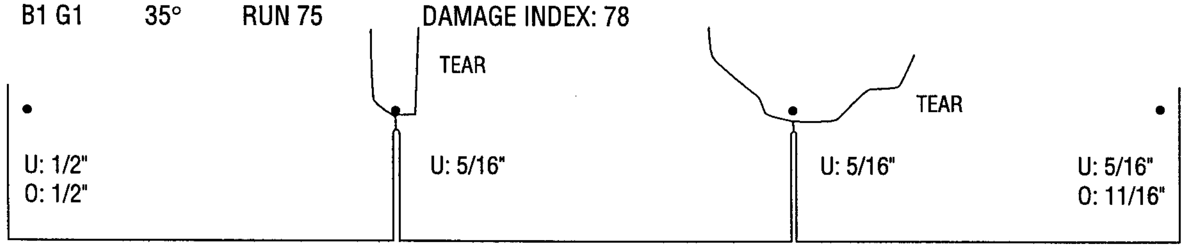
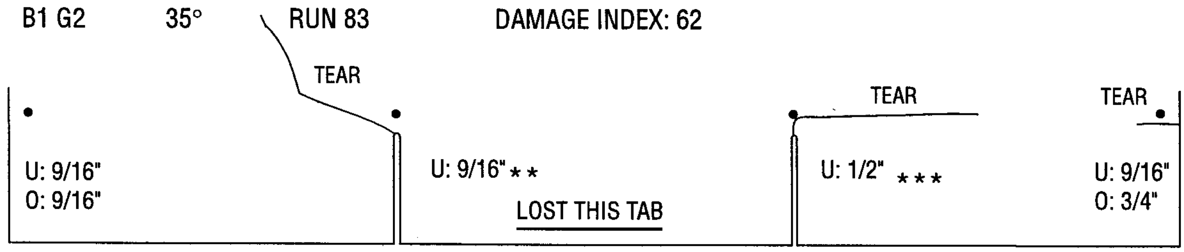


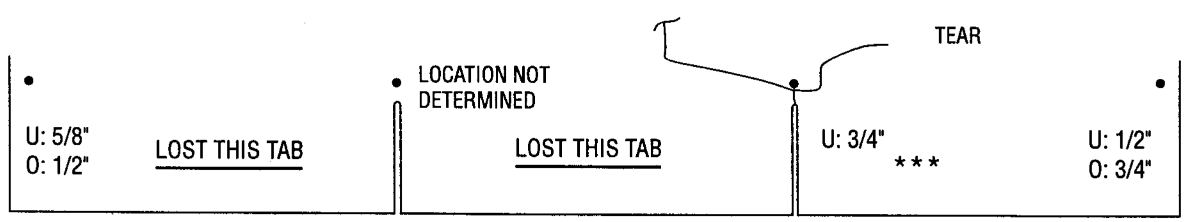

B1 G1 35° RUN 75 DAMAGE INDEX: 78



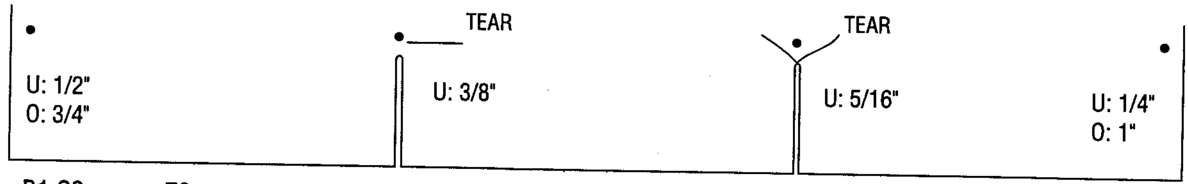

B1 G2 35° RUN 83 DAMAGE INDEX: 62



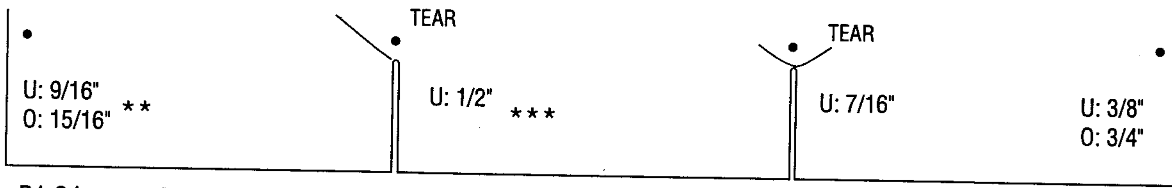

B1 G3 35° RUN 87 DAMAGE INDEX: 62



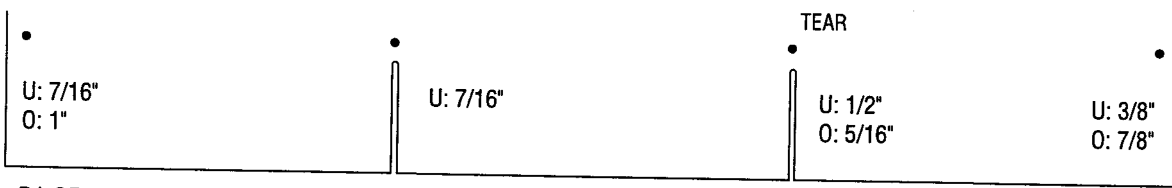

B1 G4 35° RUN 93 DAMAGE INDEX: 86



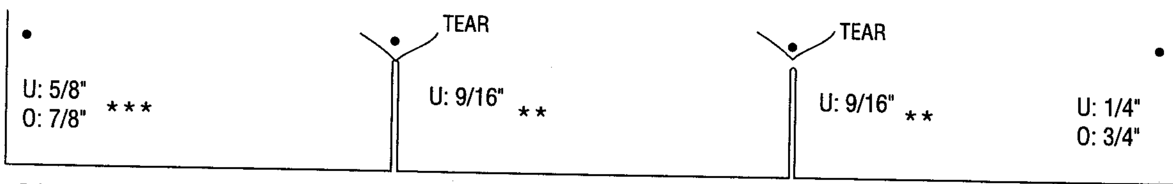

B1 C3 70° RUN 34 DAMAGE INDEX: 84



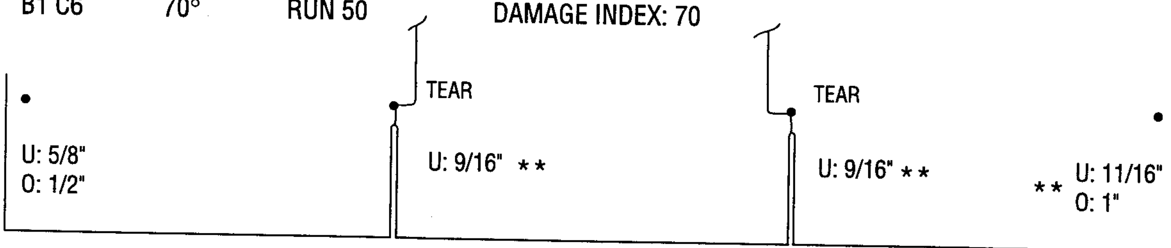

B1 C4 70° RUN 43 DAMAGE INDEX: 70



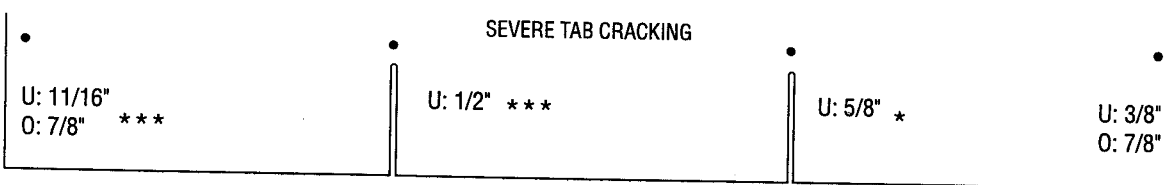

B1 C5 70° RUN 48 DAMAGE INDEX: 44



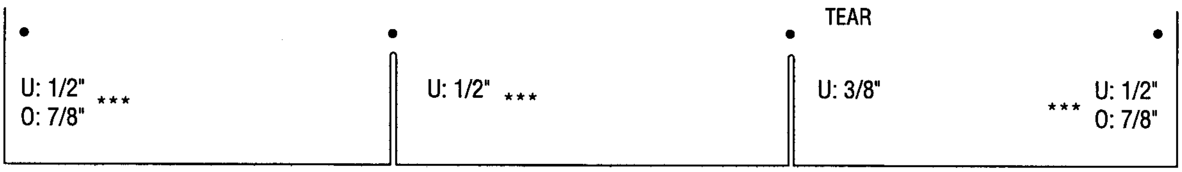

B1 C6 70° RUN 50 DAMAGE INDEX: 70




B1 C7 70° RUN 52 DAMAGE INDEX: 166

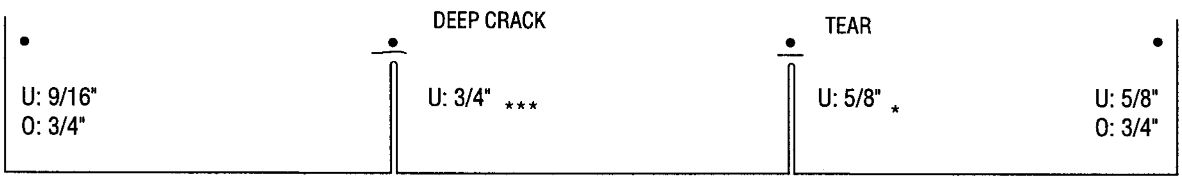



B1 C8 70° RUN 54 DAMAGE INDEX: 32

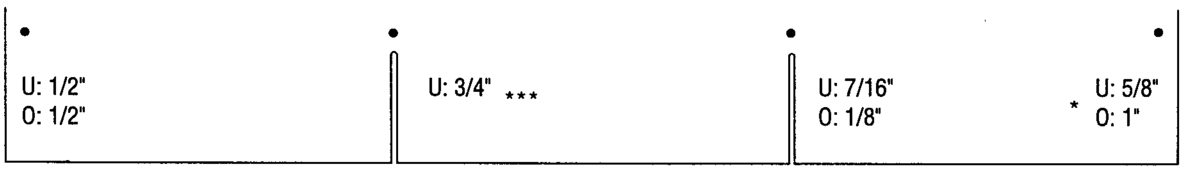



B2 C3 70° RUN 35 DAMAGE INDEX: 44

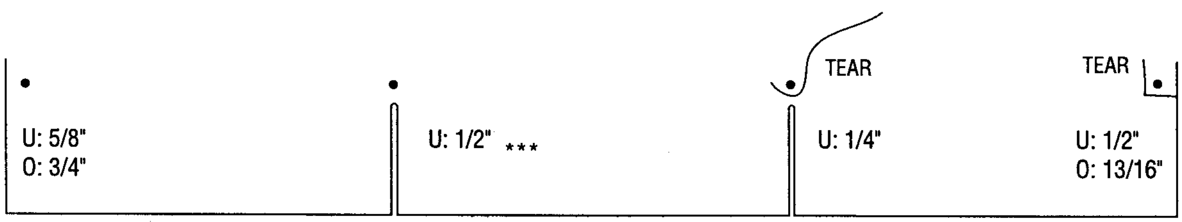

B2 C4 70° RUN 49 DAMAGE INDEX: 34



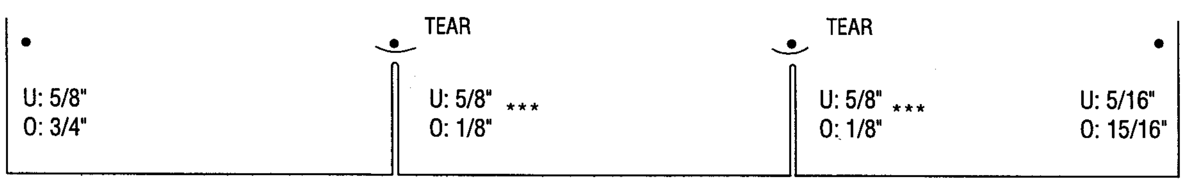

B2 C5 70° RUN 56 DAMAGE INDEX: 34



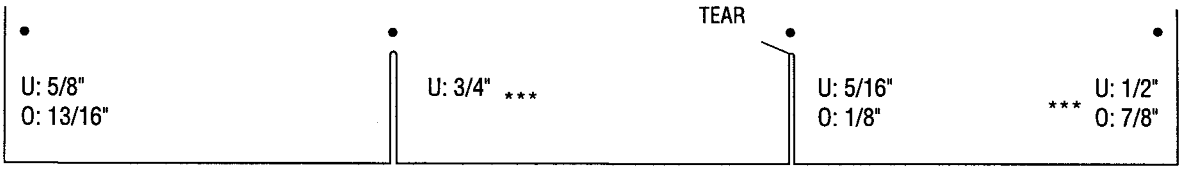

B2 C6 70° RUN 58 DAMAGE INDEX: 36



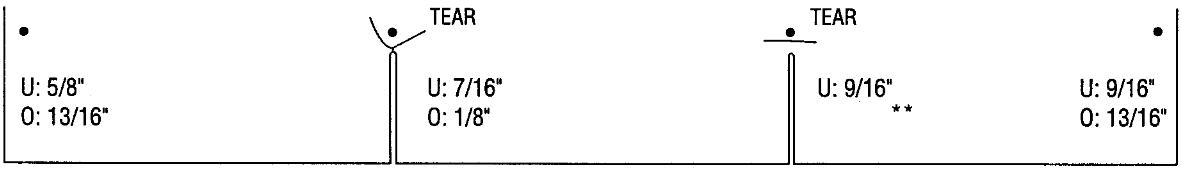

B2 C7 70° RUN 59 DAMAGE INDEX: 48



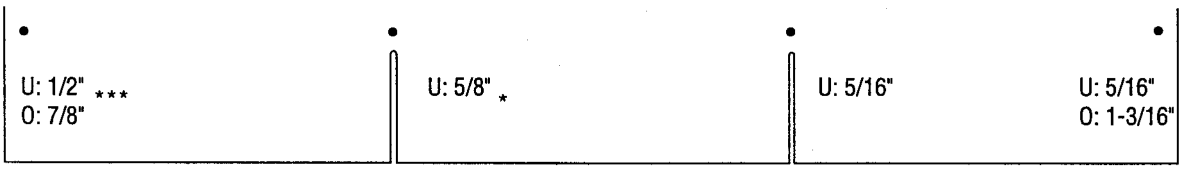

B2 C8 70° RUN 60 DAMAGE INDEX: 24




B2 D1 35° RUN 71 DAMAGE INDEX: 12




B2 D2 35° RUN 80 DAMAGE INDEX: 26




B2 D3 35° RUN 86 DAMAGE INDEX: 14 NO DAMAGE ROW 2


B2 D4 35° RUN 92 DAMAGE INDEX: 19

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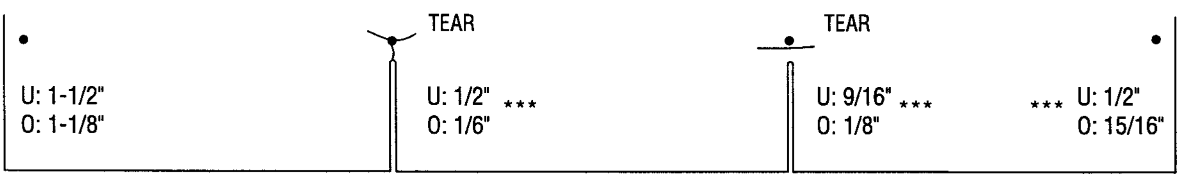
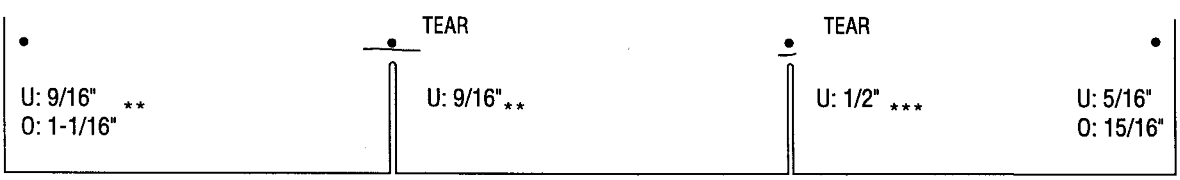
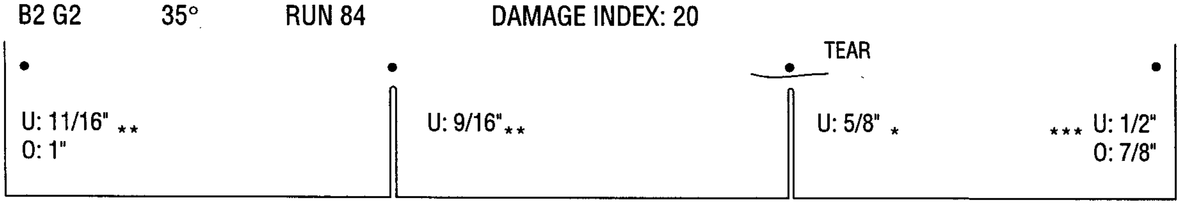


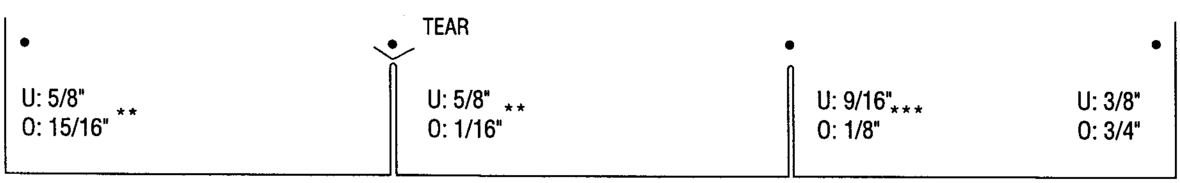

B2 G1 35° RUN 90 DAMAGE INDEX: 14



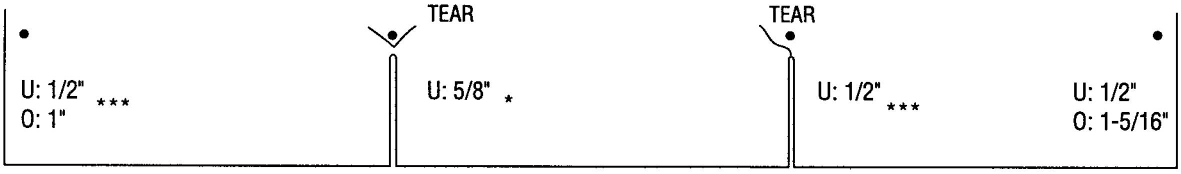

B2 G2 35° RUN 84 DAMAGE INDEX: 20



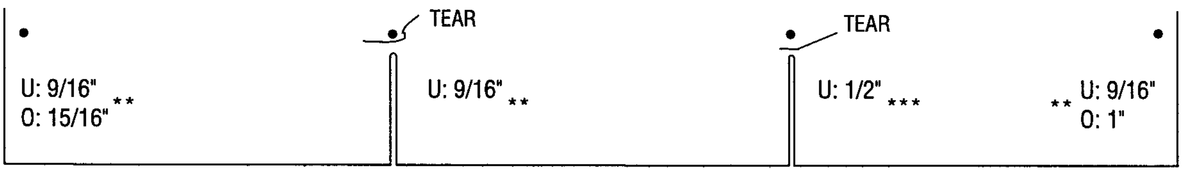

B2 G3 35° RUN 88 DAMAGE INDEX: 24



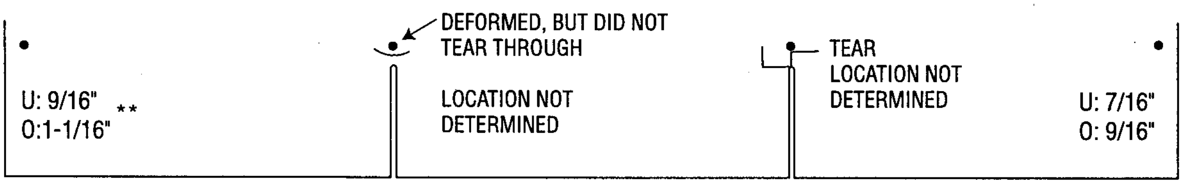

B2 G4 35° RUN 94 DAMAGE INDEX: 12




B2 H1 35° RUN 117 DAMAGE INDEX: 16 LONG DURATION

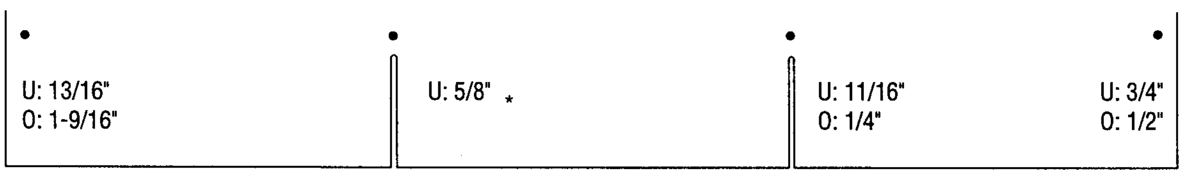



B2 H2 35° RUN 119 DAMAGE INDEX: 19 LONG DURATION

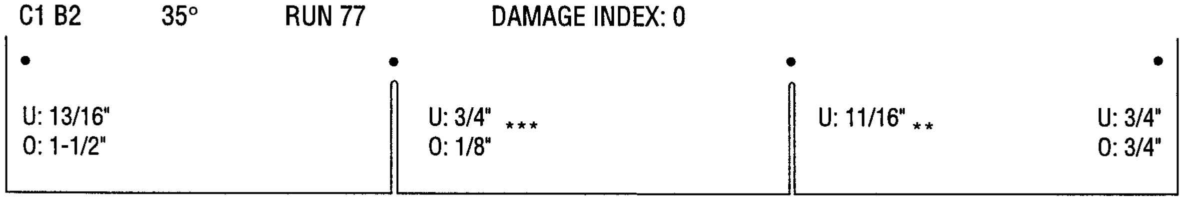



B2 H3 35° RUN 121 DAMAGE INDEX: 45 LONG DURATION


C1 B1 35° RUN 73 DAMAGE INDEX: 0

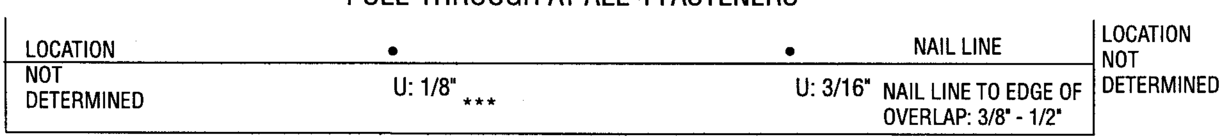



C1 B2 35° RUN 77 DAMAGE INDEX: 0

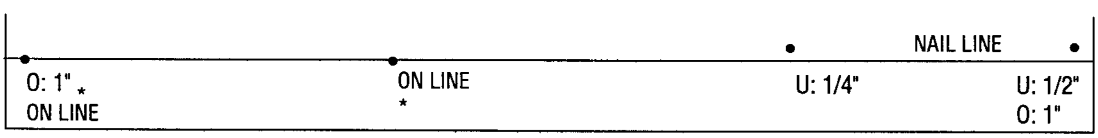



C1 B4 35° RUN 89 DAMAGE INDEX: 0

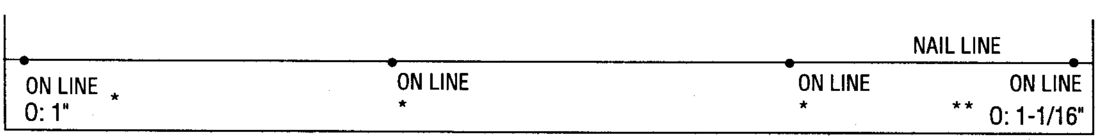
PULL-THROUGH AT ALL 4 FASTENERS




D2 A2 70° RUN 20 DAMAGE INDEX: 68




D2 A3 70° RUN 32 DAMAGE INDEX: 30




D2 A4 70° RUN 42 DAMAGE INDEX: 4