RAiNA
RAINSCREEN ASSOCIATION IN NORTH AMERICA

Cracking Under Pressure: Lessons in Accommodating In-Plane Movements

Aaron Rosen
PE, RBEC®, REWC®
RosenBEC

Spencer Anderson
BME
American Fiber Cement

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Presenter Bio

Aaron Rosen
PE, RBEC®, REWC®
Principal at RosenBEC

Aaron Rosen is a principal at the building enclosure consulting firm RosenBEC. His certifications include Professional Engineer (PE), Registered Building Enclosure Consultant (RBEC®), and Registered Exterior Wall Consultant (REWC®). He has over 20 years of professional experience working with many different types of cladding systems. Aaron has been retained numerous times to provide a third-party expert opinion on a variety of building enclosure related issues. RosenBEC has been providing building enclosure consulting services on high-end projects across the United States since 2016.

Presenter Bio

Spender Anderson
BME
Technical Director at
American Fiber Cement

Spencer Anderson is the Technical Director for American Fiber Cement with 10 years of experience in the cladding industry. He has experience working in all areas of the building envelope from attachment system and cladding design to installation. He has reviewed numerous fiber cement cladding installations. Spencer has a B.S. Degree in Mechanical Engineering from Clemson University with a Fundamentals of Engineering Certification.

Abstract

There are numerous considerations when designing an exterior wall system clad with fiber cement panels. Manufacturers typically provide guidelines with respect to proper detailing and installation so the panels can function as intended. This includes structural attachment, movement accommodations, airflow, and weatherability considerations.

This presentation will cover a variety of topics such as building science considerations, building enclosure performance attributes, and general design guidelines. Real-world examples of non-compliant conditions will also be discussed, as well as an overview of the resulting consequences. Photographs taken from forensic investigations will be shared so the attendees can visually compare the differences between the design guidelines versus problematic as-built conditions.

These case studies are good examples of how deviations from installation guidelines can result in detrimental performance, expensive repairs, and disputes amongst stakeholders. These case studies will provide lessons learned for the benefit of architects, engineers, and contractors to help them from making similar mistakes.

Learning Objectives

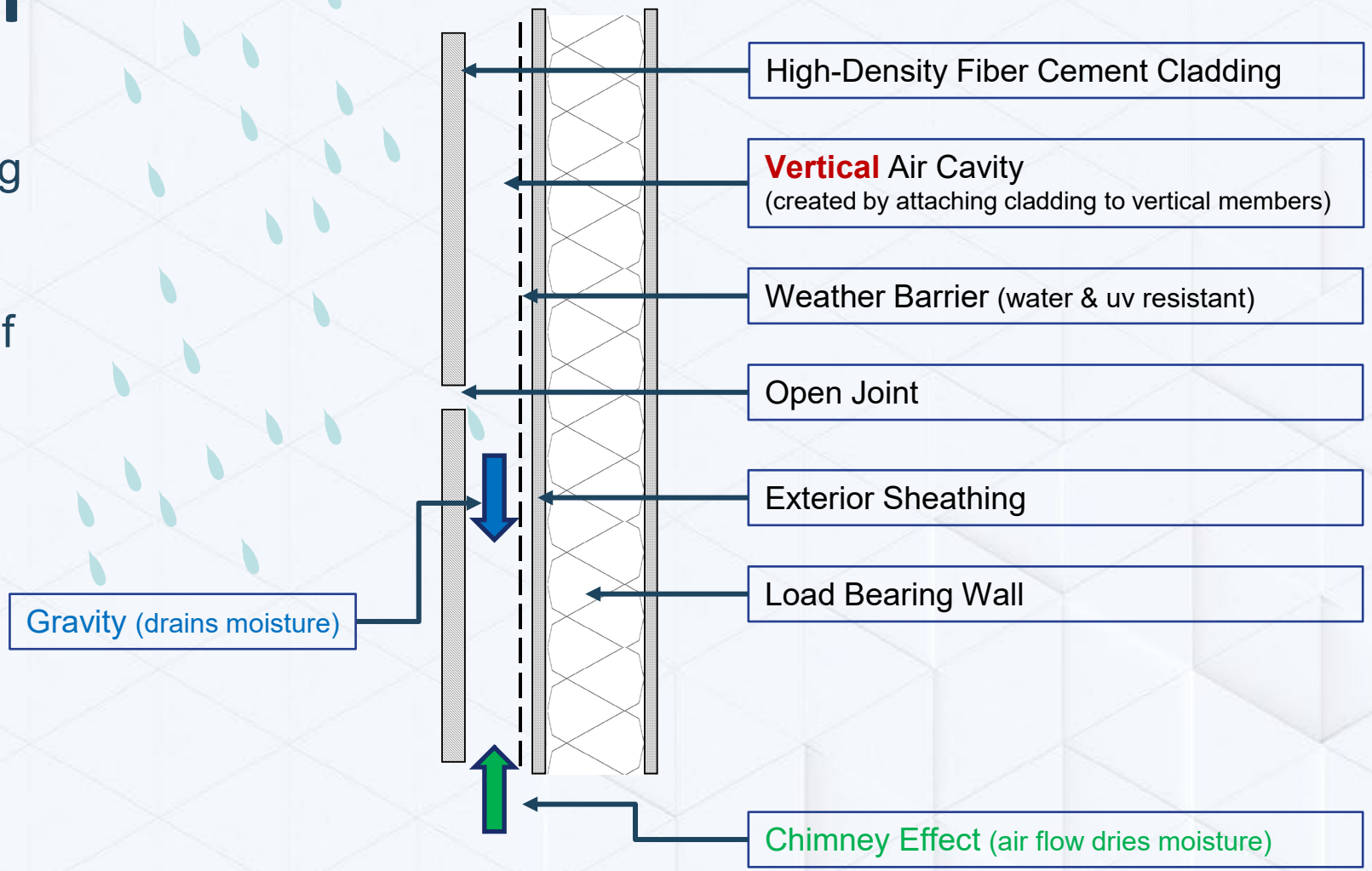
1. Explain the impact temperature and moisture has on fiber cement exterior wall panels.
2. Describe the difference between fixed and gliding anchor connection points
3. Determine the appropriate location and edge spacing of the anchor connection points.
4. Understand rainscreen airflow and how it properly dries the wall panels.

What is High-Density Fiber Cement?

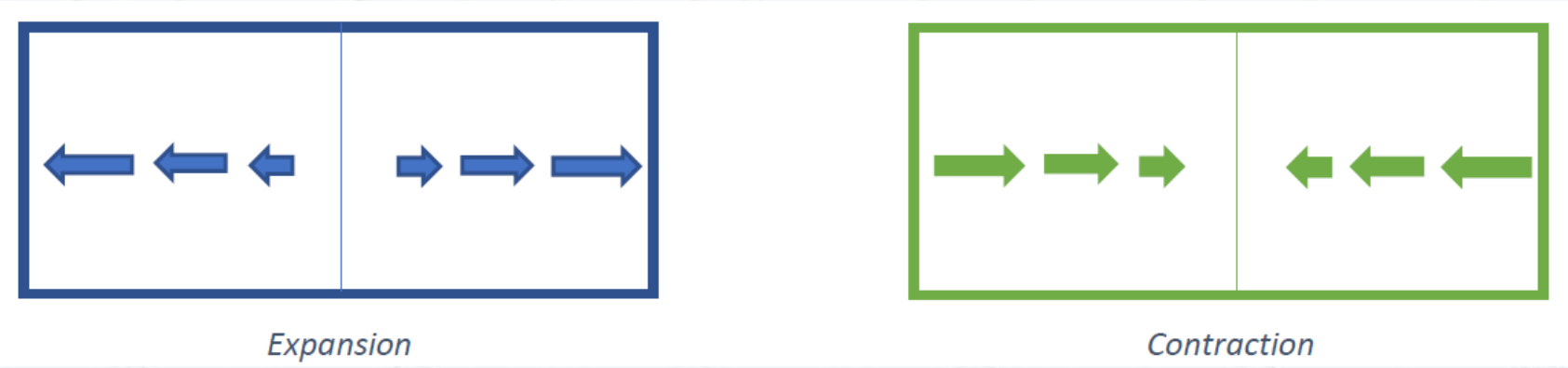
- Uses: Europe – Sheathing, Roofing, Exterior Cladding;
  USA – Exterior Cladding
- Panel Thickness: 8mm
- Panel Size: 4’x8’ or 4’x10’
- Lifespan: 50+ years
- Features: Frost Resistant, Low maintenance Noncombustible, High Bending Strength, Low Weight (~3 psf)

Rainscreen System

- Prevents water from penetrating the load bearing structure.
- Keeps the front and backside of the fiber cement panel in equilibrium.



Fiber Cement Expansion/Contraction

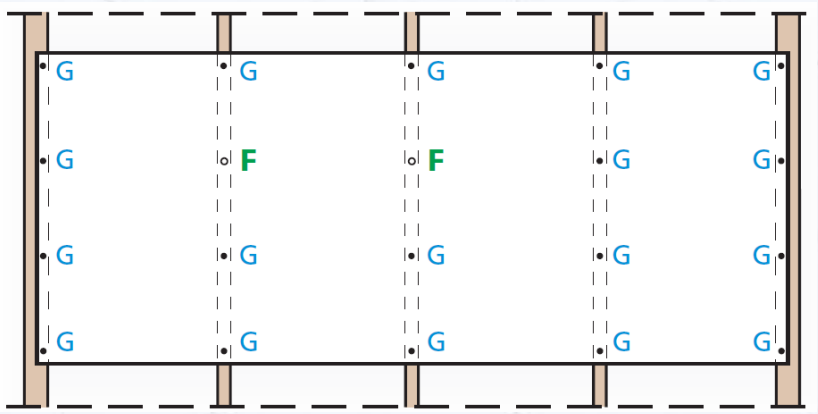


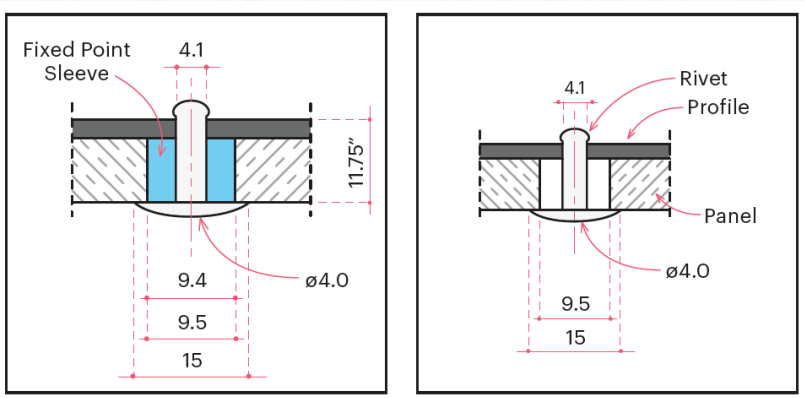
Affected by Change in Moisture and Temperature

- Coefficient of Thermal Expansion: 0.01 mm/(m x ºC)
- Moisture Movement (30 to 90% RH): 0.8mm/m

Fiber Cement Expansion/Contraction

Design Strategies

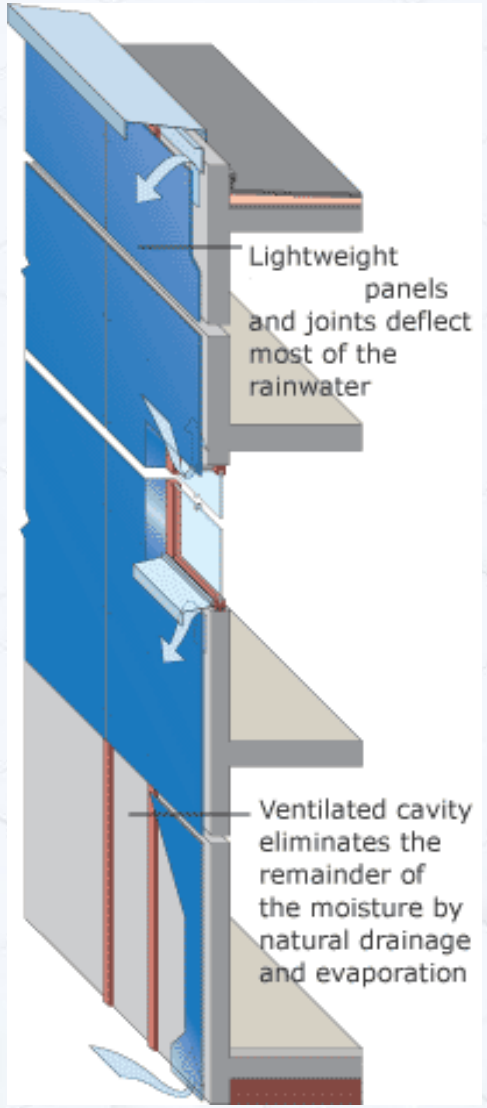




Fixed Point — cylinder & rivet

Gliding Point — cylinder & rivet

- Fixed/gliding point attachment system



- Airflow via the chimney effect

Expansion/Contraction Modes of Failure

Incorrect Hole Sizes

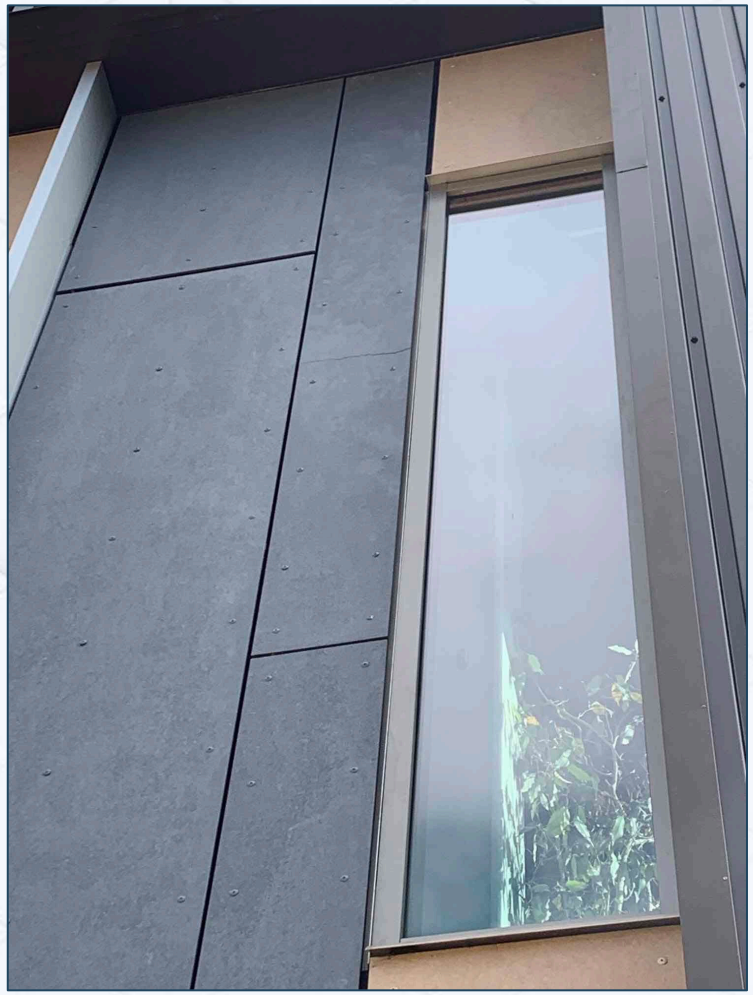
- Excessive number of Fixed Points leads to cracking

Expansion/Contraction Modes of Failure

Incorrect Hole Sizes

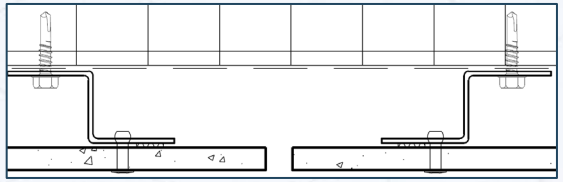
- Excessive number of Fixed Points leads to cupping

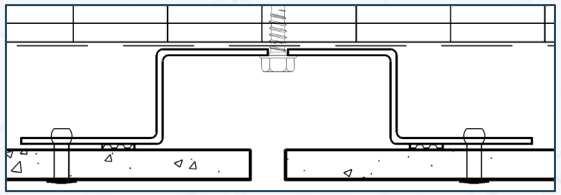
Expansion/Contraction Modes of Failure

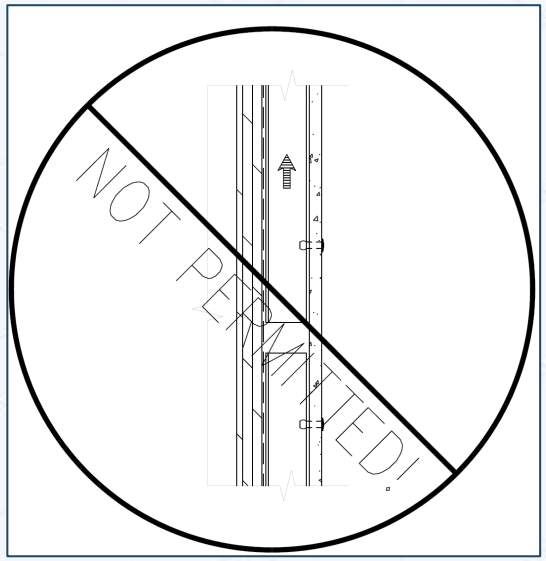


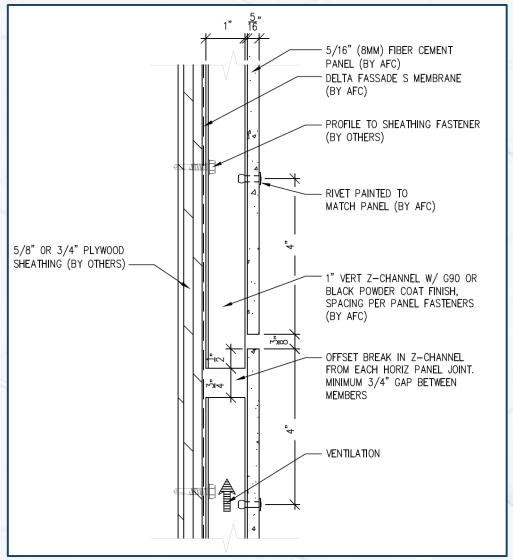
Panel Spans a Profile Break

- Profiles also expand and contract
- Causes a horizontal crack
- Often occurs with a vertically oriented staggered layout when using inverse hat profiles
- Incorrect and Correct Details:





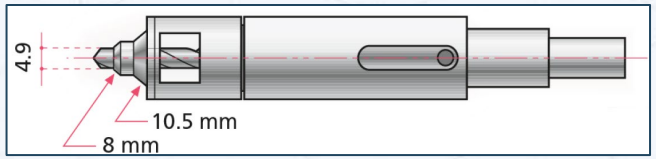




Expansion/Contraction Modes of Failure

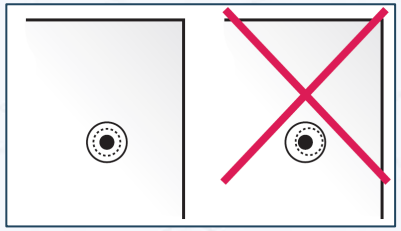
Gliding Points not Centered

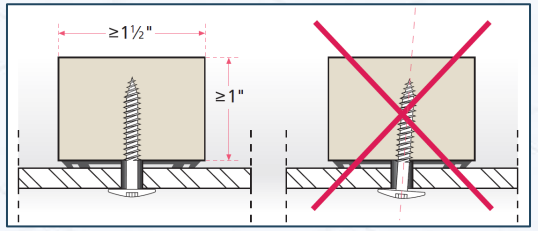
- Rivet Intallation



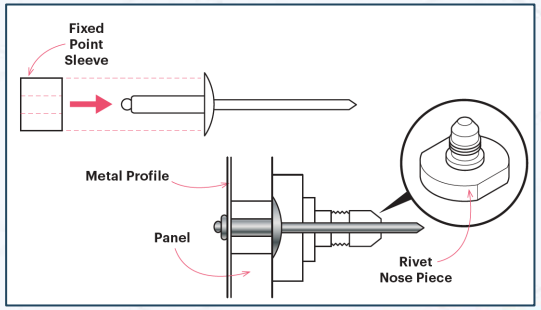
Centralizing Drill

- Screw Installation





Overtightened rivet or screw



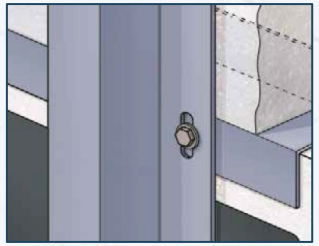
Expansion/Contraction Modes of Failure

- Substructure out of plumb

Overlapping profiles and protruding screw heads

Plumb the profiles, not the panel

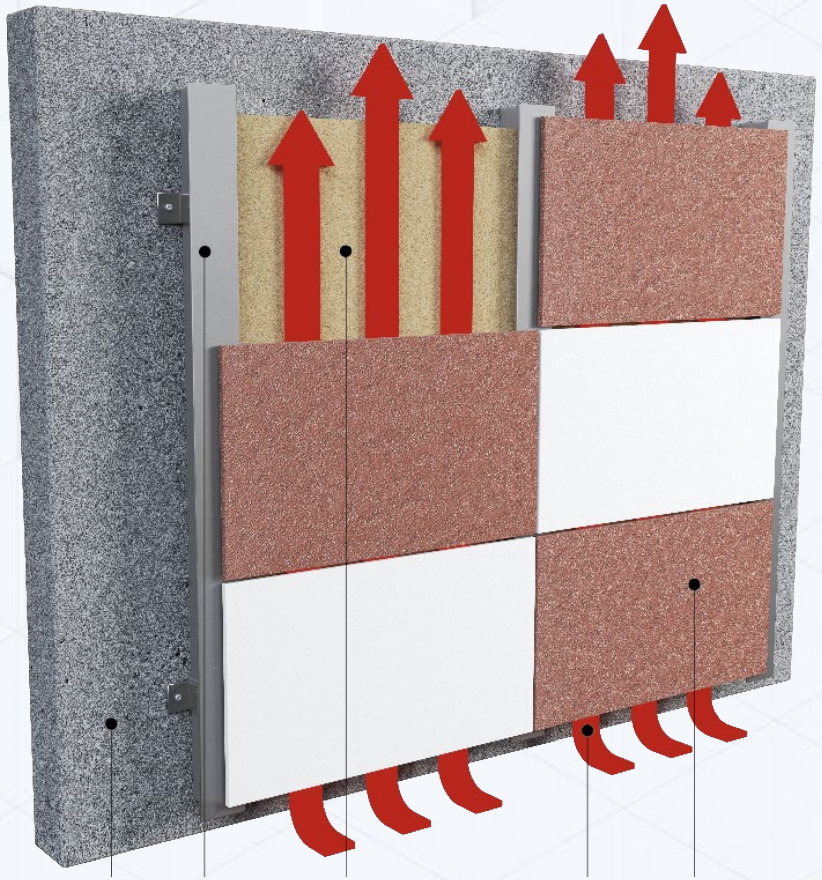
- Panel spans floor line expansion joint



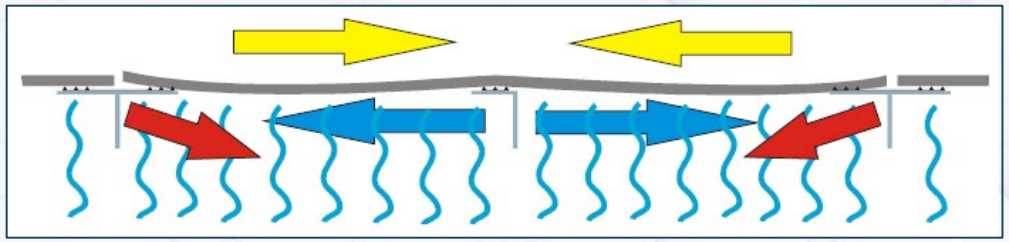
Slotted fastener hole

Fiber Cement Airflow

- Goal: Have the front side and backside dry and cool at equal rates. This is achieved via the chimney effect.



- Limited Airflow: Front side is exposed and can dry quickly from airflow and the sun. The sun heats the panel up and creates a hot humid air cavity. The panels expand with moisture and heat. This creates an inward cup with pressure points at the profiles.

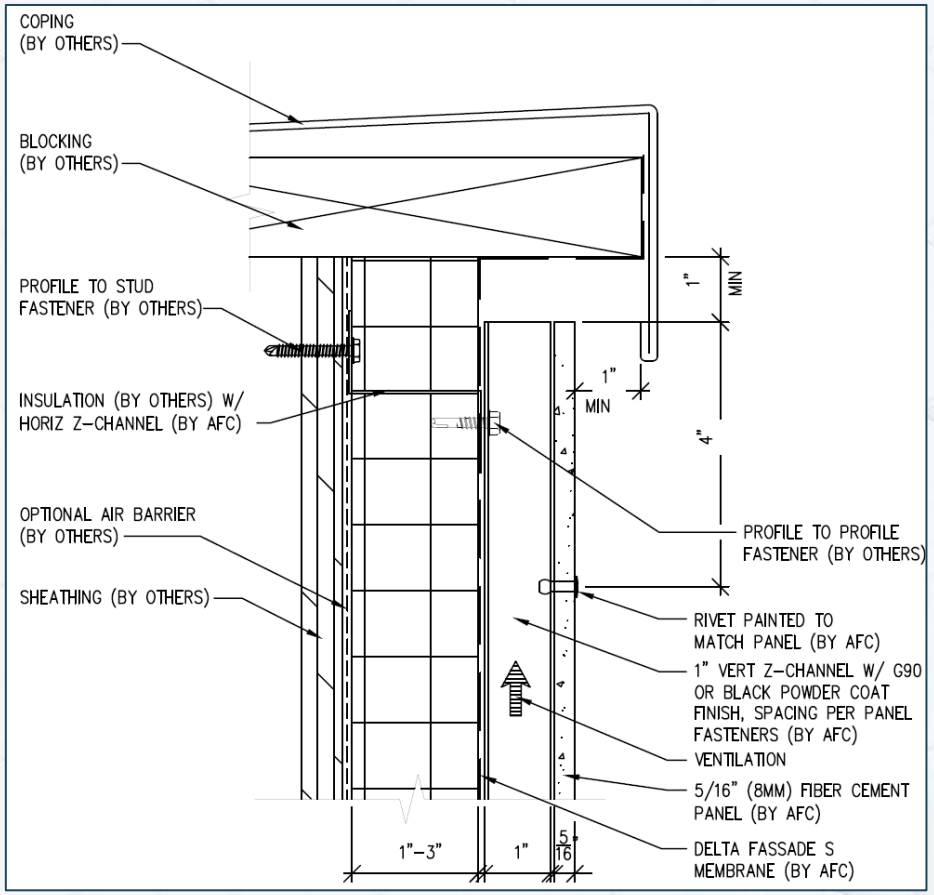


Fiber Cement Airflow

Inward Cupping - Example

Fiber Cement Airflow

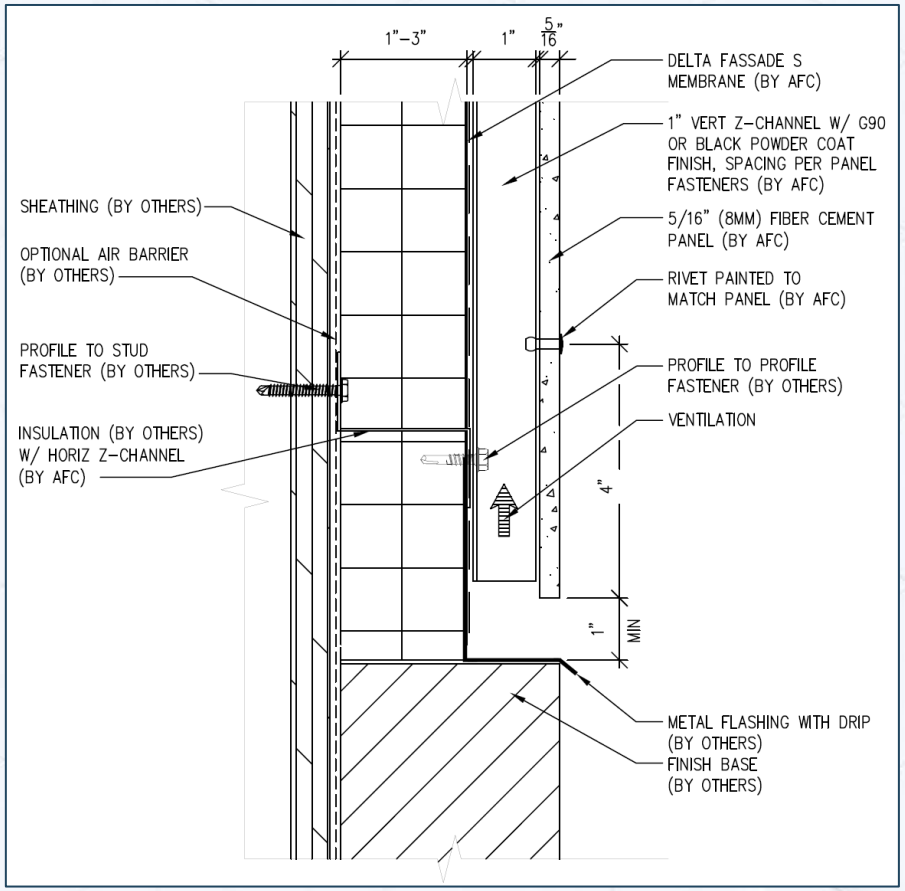
Parapet Opening Blocked



Correct Detail

Fiber Cement Airflow

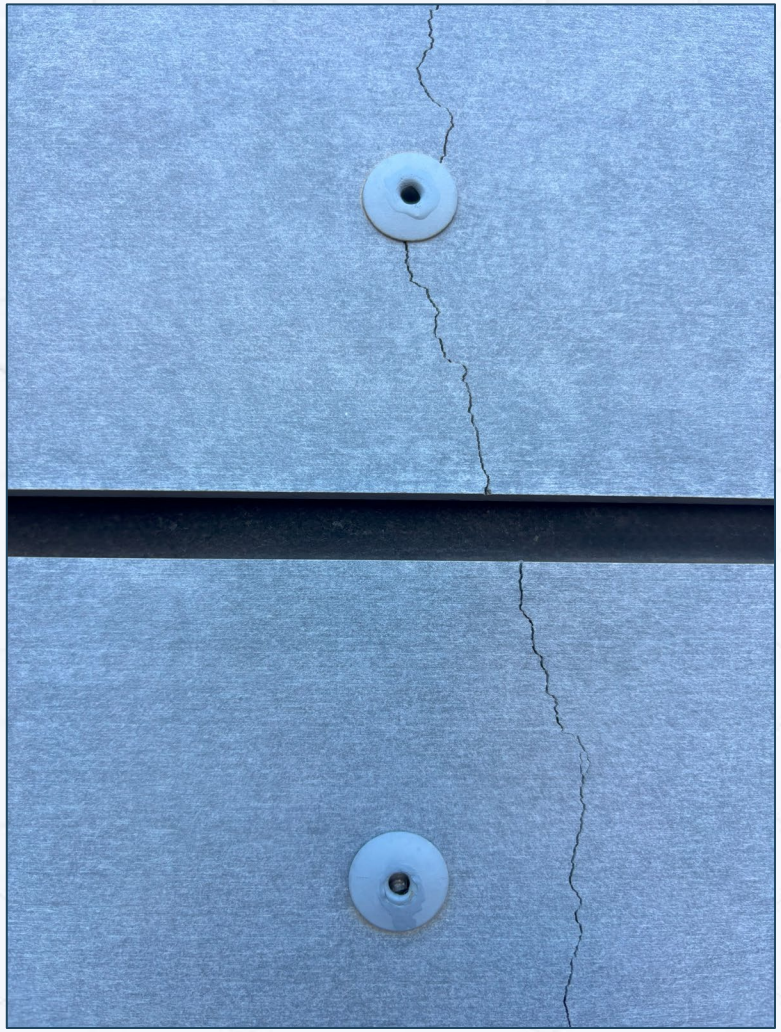
Base Opening Blocked

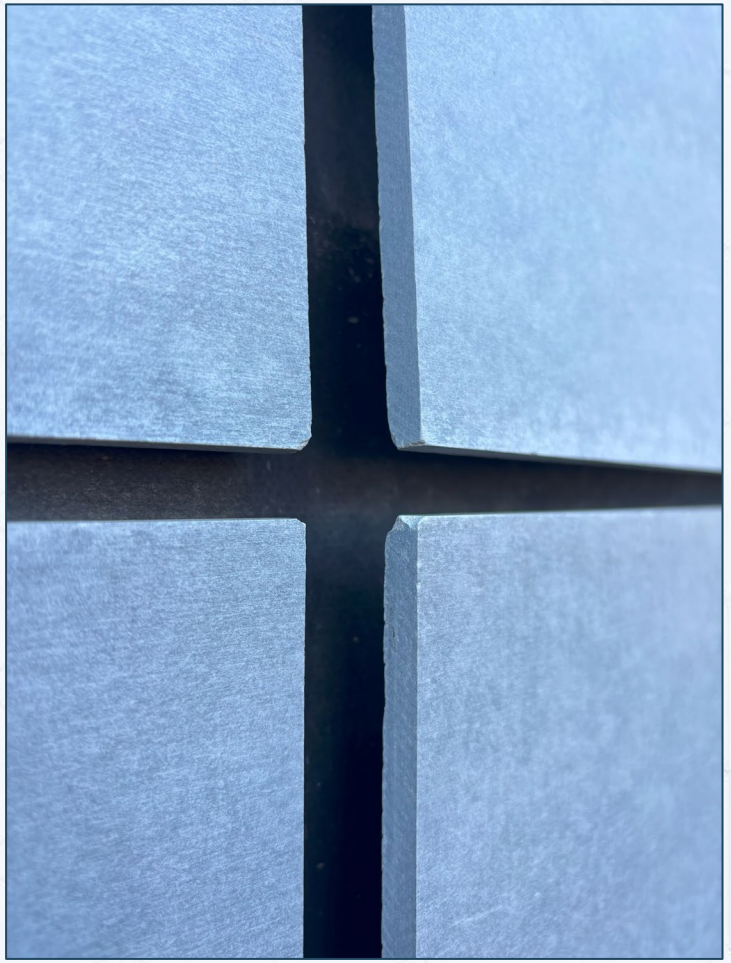


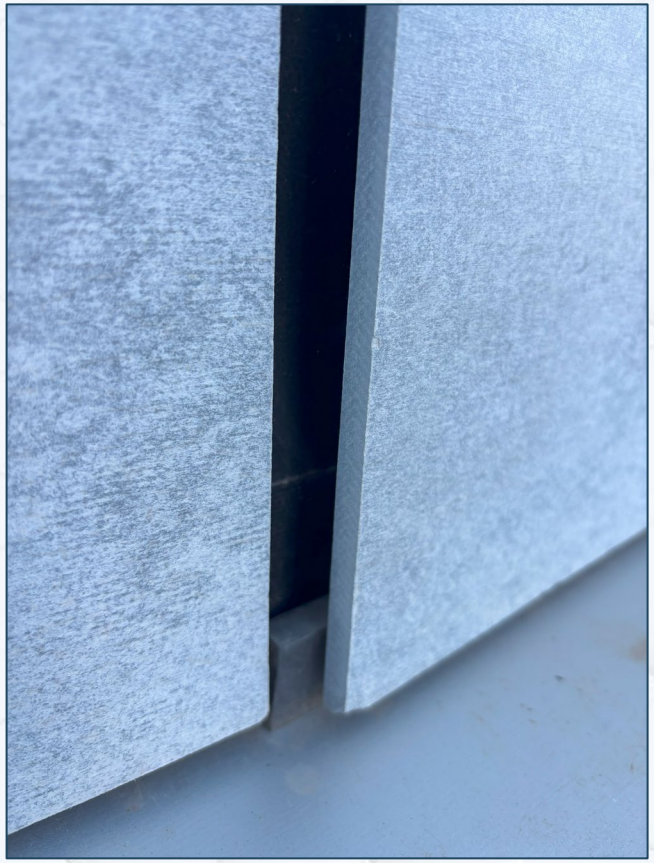
Correct Detail

Fiber Cement Airflow

Weather Barrier Outboard of Profiles







Fiber Cement Airflow

Vents/Bug Screens at Panel Base

- Must be at least 50% open.
- Should only be used if all joints are closed off and mineral wool is covered with a weather barrier.
- An open air-cavity that allows water and airflow will be less prone to have bugs than a “mostly closed off one” with no airflow.

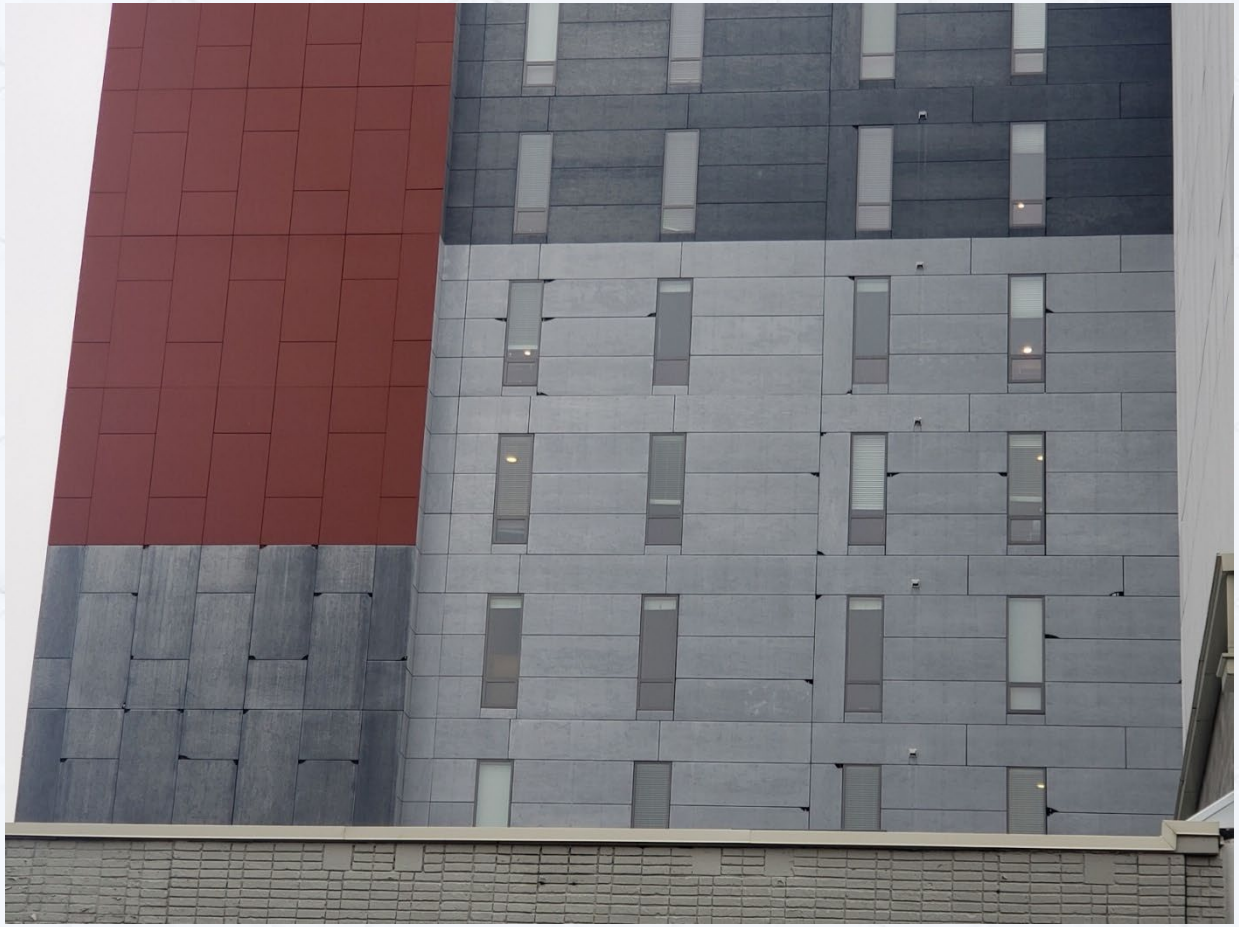
Outlook

- Fiber Cement Manufacturers are aware that all installations are not perfect. Steps are being taken to reduce moisture movement through hydrophobic coating improvements.
- As rainscreen systems have become more common in the United States, architects have begun to fully understand the installation requirements and are detailing the system appropriately.
- Through experience, installation companies are also understanding the system better.
- Shop drawings prevent hole drilling issues and gives the manufacturer a second change to review and modify installation details.
- Technical support and installation videos are all helping to avoid installation issues.

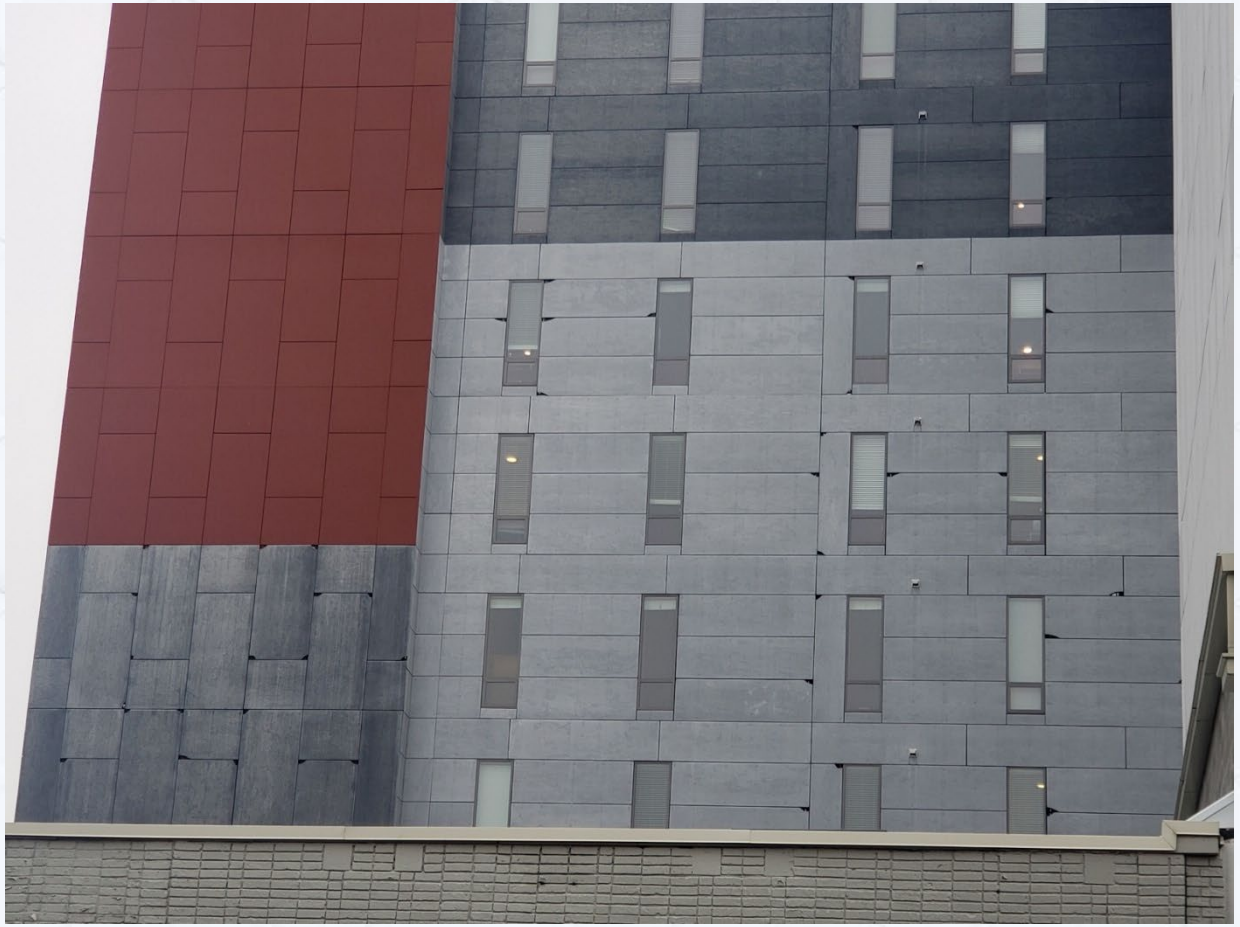
Case Study #1

- Building Occupancy: Apartment building (178-units).
- Building Size: 10-story (approximately 232,000 ft^2).
- Initial Concern: Approximately 5 years after substantial completion, cracked wall panels were identified during routine maintenance of the exterior façade.
- Initial Survey: A drone survey revealed approx. 400 of the nearly 5,000 panels were cracked.
- Follow Up Surveys: An additional 300 cracked panels were identified over the next 2 years.

Representative Panel Cracking

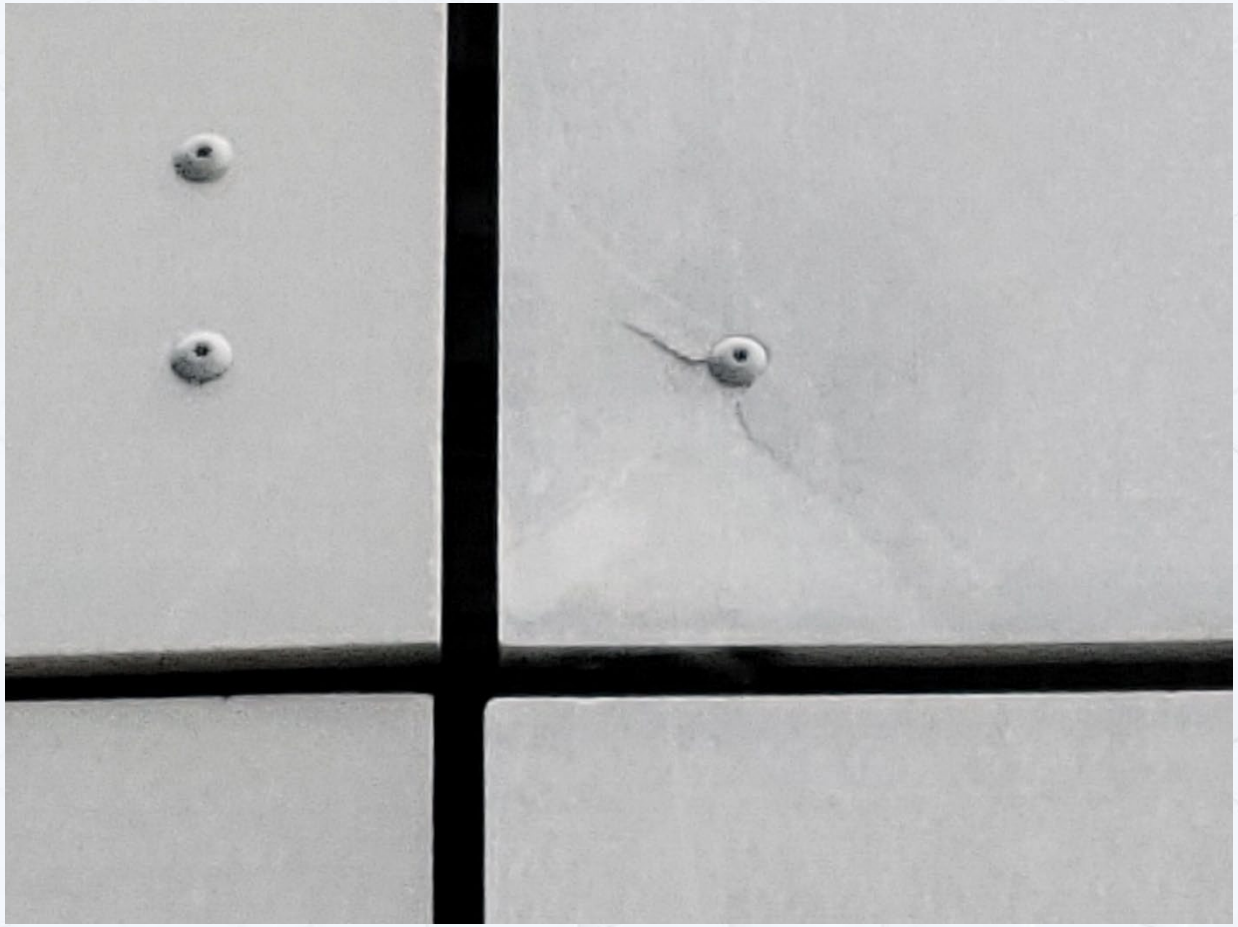


Representative Panel Cracking



Representative Panel Cracking

Representative Panel Cracking



Representative Bowing

Representative Anchor

Representative Anchor

Failure Analysis

- Screws were installed in lieu of rivets.

[redacted] Installation Guidelines prohibit the use of screws for attaching panels onto metal profiles. Rivets supplied by [redacted] must be used when the substructure is metal. Screws may only be used on wooden profiles. [redacted] standard installation guidelines for Aluminum and Steel profiles can be found at [redacted]. Here are the reasons why rivets must be used with metal applications.

1. Screws can be installed misaligned with the center point of the hole. With a rivet gun, a centralizing tool can be used to ensure every rivet is centered within the hole. This will allow the panel to expand and contract freely.

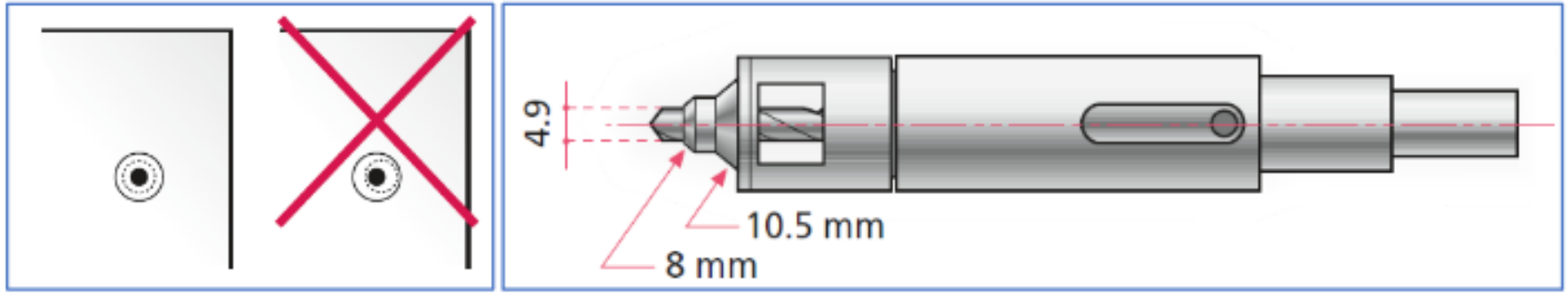


Figure 1: Aligned Hole vs. Misaligned Hole | Figure 2: [redacted] Centralizing Tool

Failure Analysis

- Screws were installed in lieu of rivets.

[redacted] Installation Guidelines prohibit the use of screws for attaching panels onto metal profiles. Rivets supplied by [redacted] must be used when the substructure is metal. Screws may only be used on wooden profiles. [redacted] standard installation guidelines for Aluminum and Steel profiles can be found at [redacted]. Here are the reasons why rivets must be used with metal applications.

2. Screws can be installed at an angle that is not perpendicular to the metal profile. This will also block panel expansion and contraction. The collar on a rivet rests flat up against the metal so it cannot be installed at an angle.

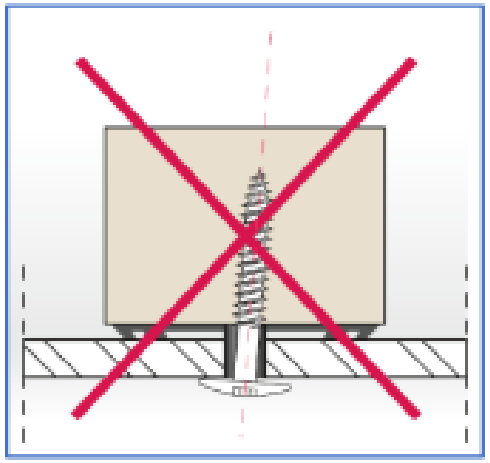


Figure 3: Screw Installed at an Angle

Failure Analysis

- Screws were installed in lieu of rivets.

[redacted] Installation Guidelines prohibit the use of screws for attaching panels onto metal profiles. Rivets supplied by [redacted] must be used when the substructure is metal. Screws may only be used on wooden profiles. [redacted] standard installation guidelines for Aluminum and Steel profiles can be found at [redacted]. Here are the reasons why rivets must be used with metal applications.

3. Screws can loosen overtime with temperature change cycles. Changes in temperature cause the metal to expand and contract. After this occurs a number of times, it can cause the screw to back out of the profile.

Failure Analysis

- Screws were installed in lieu of rivets.

[redacted] Installation Guidelines prohibit the use of screws for attaching panels onto metal profiles. Rivets supplied by [redacted] must be used when the substructure is metal. Screws may only be used on wooden profiles. [redacted] standard installation guidelines for Aluminum and Steel profiles can be found at [redacted]. Here are the reasons why rivets must be used with metal applications.

4. Panel movement will be improved. The [redacted] metal attachment system utilizing a rivet with a collar and foam tape allows the panel to move in three dimensions (X, Y, and Z axis). A panel fastened with a screw, at best, will only allow panel movement in two dimensions (X and Y axis). The collar on the [redacted] rivet rests up against the metal profile when it is pulled. This prevents it from overtightening. An overtightened screw will hinder panel movement in all three directions, which will lead to cracking.

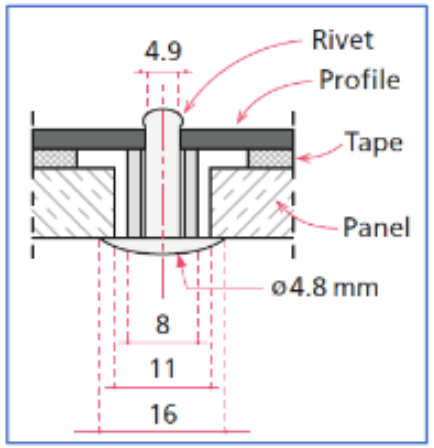


Figure 4: Rivet collar rests flat against profile

Failure Analysis

- Holes were approximately the same size.

- Average Hole Size: 5.5 mm
- Maximum Hole Size: 5.7 mm
- Minimum Hole Size: 5.2 mm

Failure Analysis

- Holes were approximately the same size.

- Average Hole Size: 5.7 mm
- Maximum Hole Size: 6.2 mm
- Minimum Hole Size: 5.4 mm

Failure Analysis

- Holes were approximately the same size.

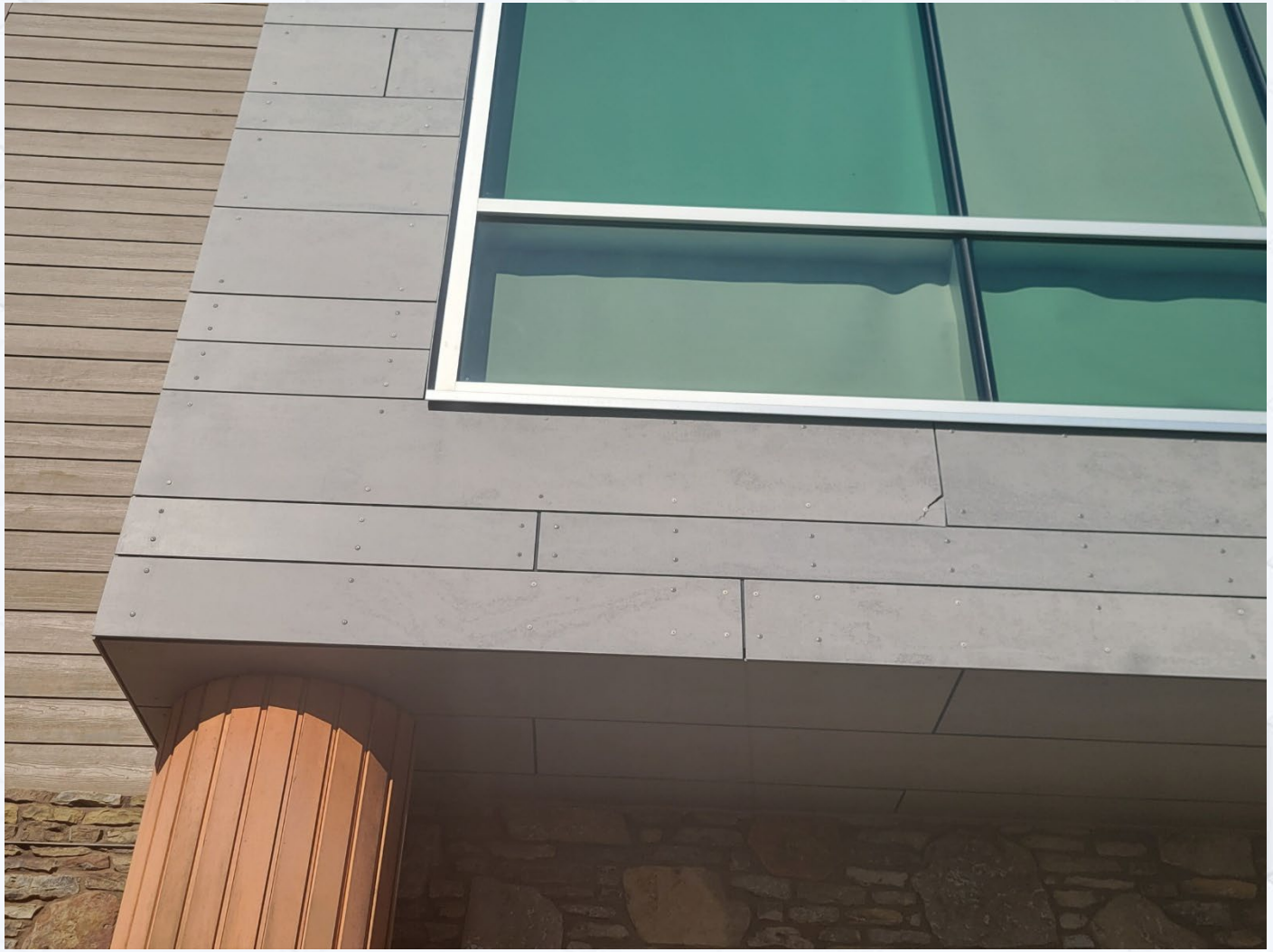
- Average Hole Size: 7.1 mm
- Maximum Hole Size: 8.5 mm
- Minimum Hole Size: 6.5 mm

Case Study #2

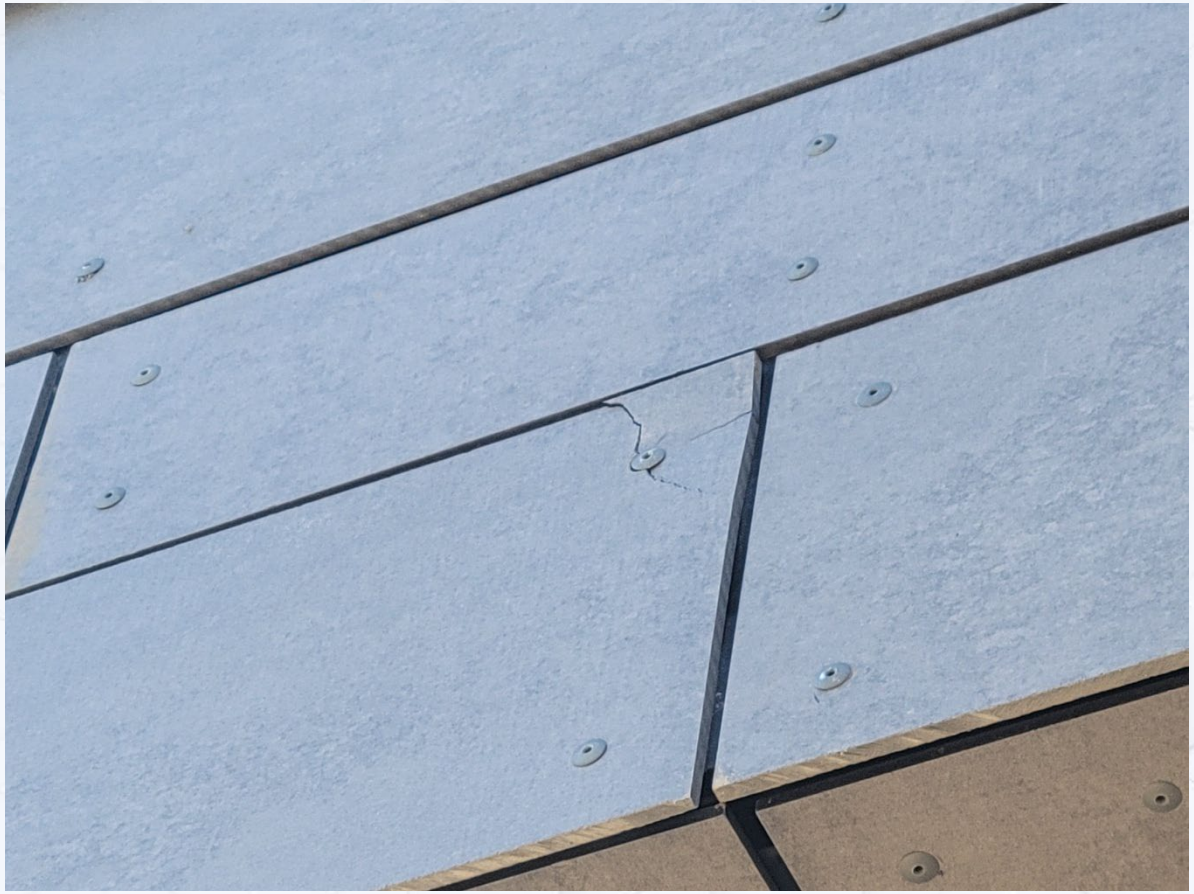
- Building Occupancy: Pediatric outpatient center.
- Building Size: 3-story (approximately 54,000 ft^2).
- Initial Concern: Approximately 2 years after substantial completion, a cracked wall panel was identified after a small piece had fallen to the ground.
- Initial Survey: The entire building was then surveyed and there were a total of 8 cracked panels.
- Follow Up Survey: Another survey was conducted about a year later and the number of cracked panels had increased to 32.

Representative Cracking

Representative Cracking

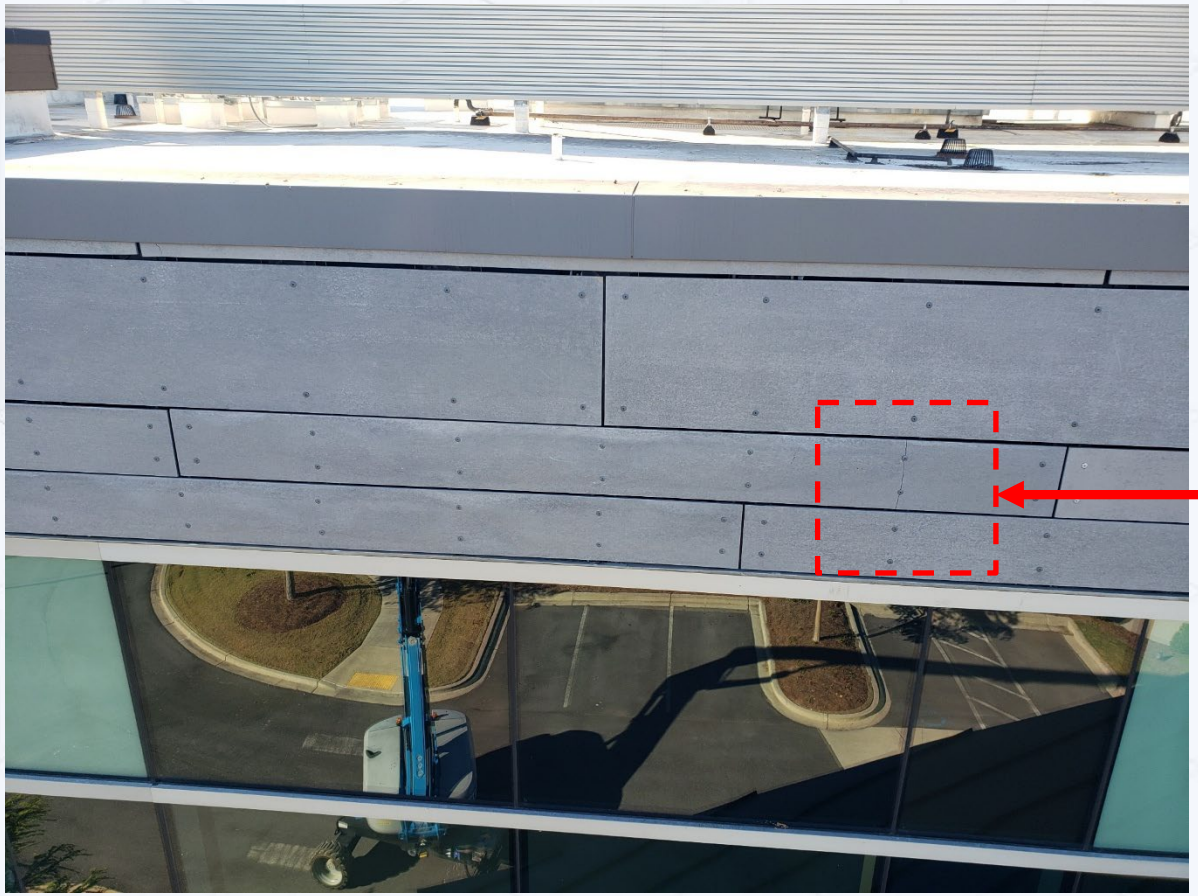


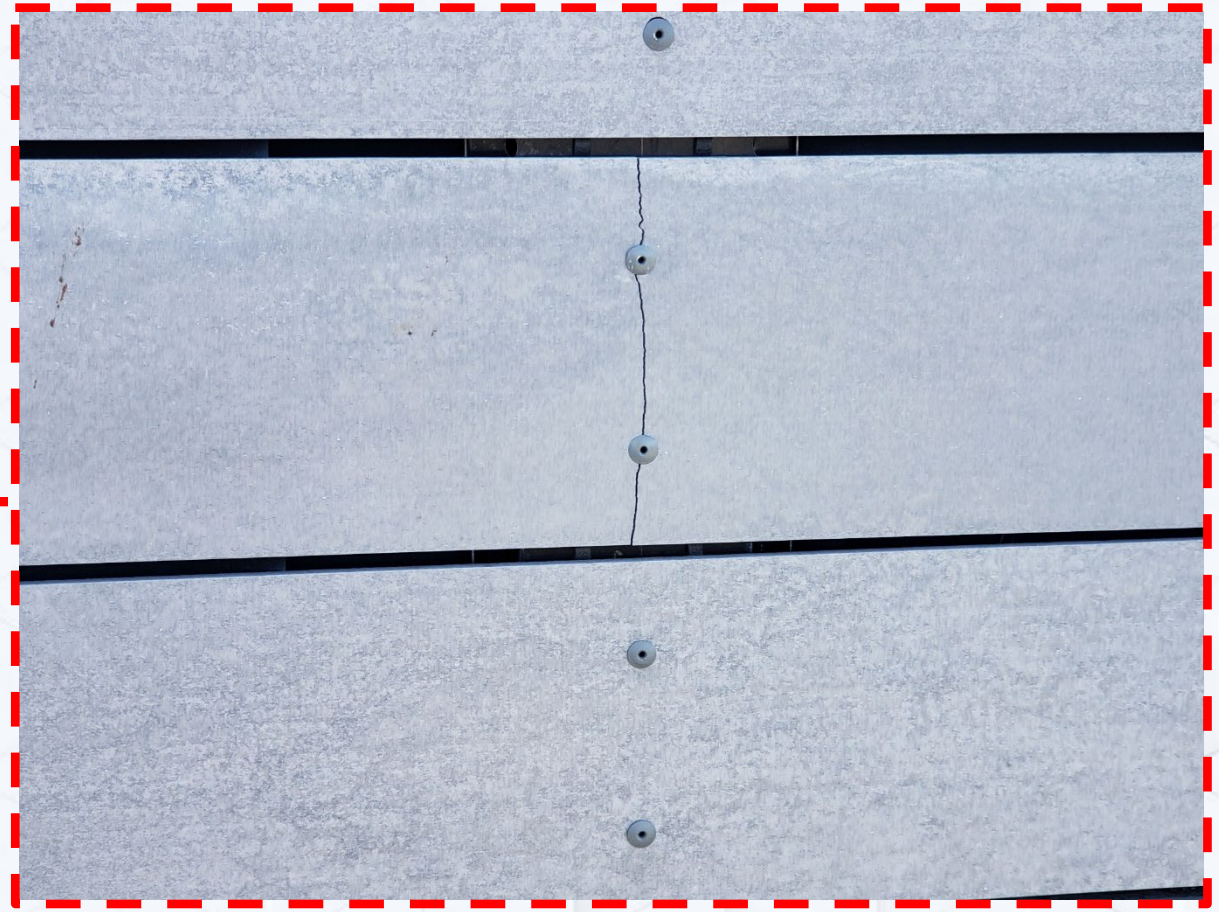
Representative Cracking



Representative Cracking

Representative Cracking

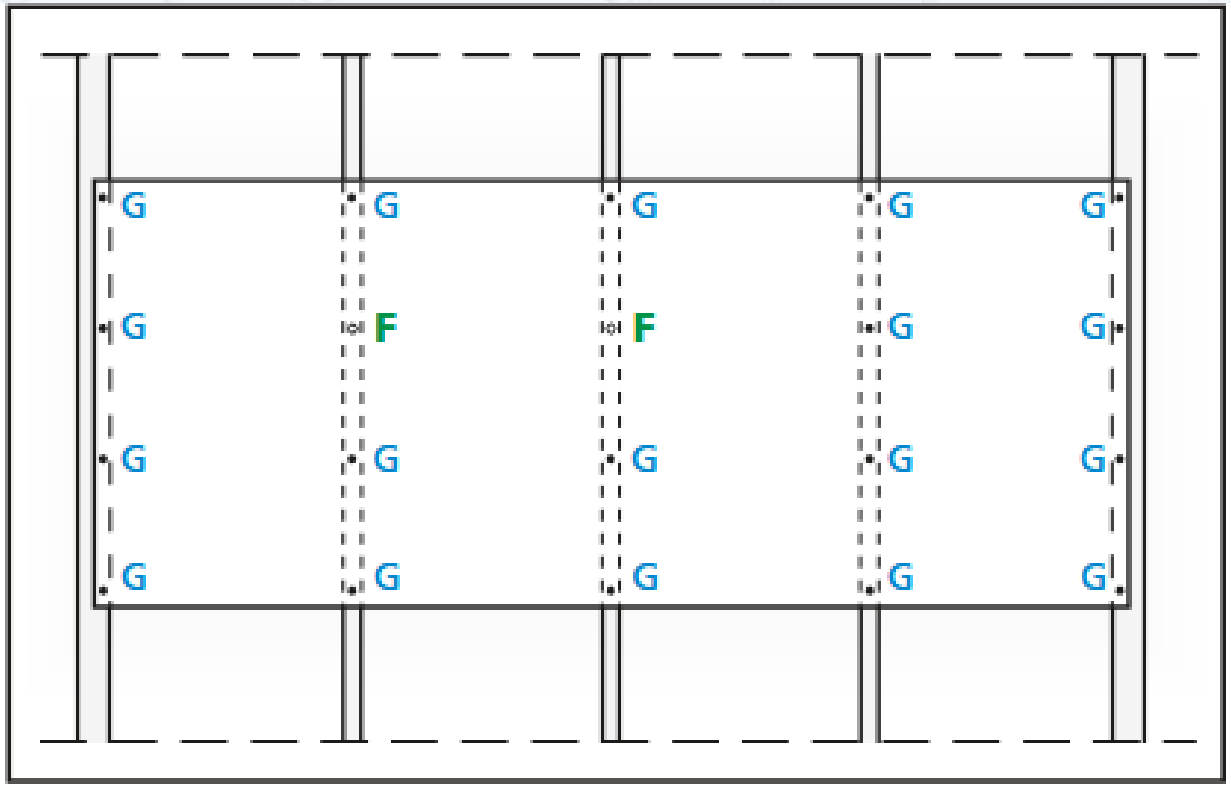


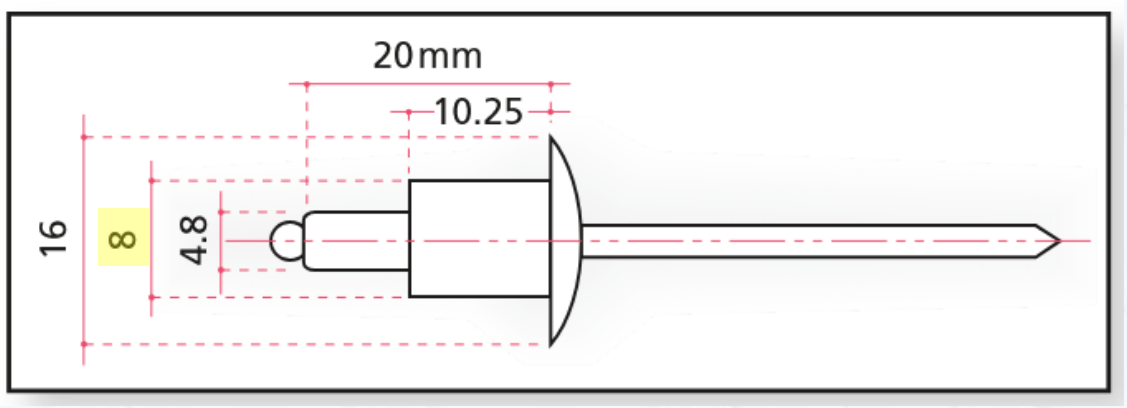


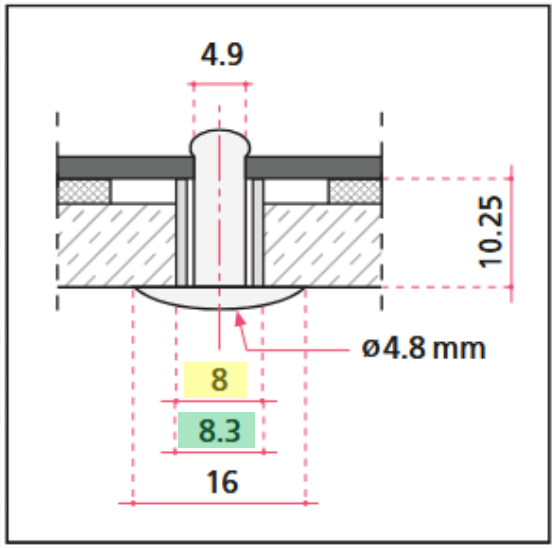
Representative Anchor

Representative Anchor

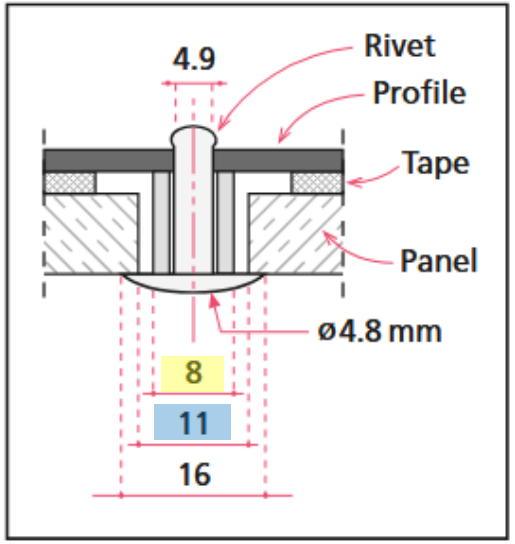
Anchorage Requirements







Fixed Point *— cylinder & rivet*



Gliding Point *— cylinder & rivet*

Diameter of the fixed point hole is to be 8.3 mm (21⁄64").
Diameter of the gliding point hole is to be 11 mm (7⁄16").

Hole Measurements

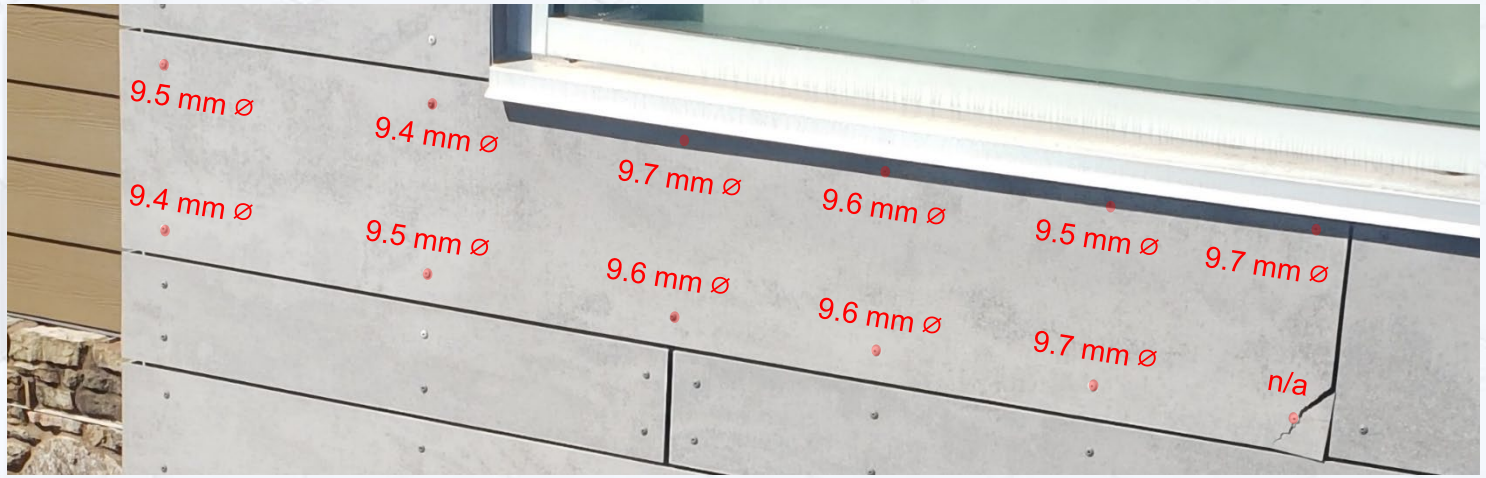
Specified Hole Diameters

- Fixed Points: 8.3 mm
- Gliding Points: 11 mm

Categorization of Field Measurements

- It would seem plausible for there to be slight differences in the actual hole diameters, so an ***arbitrary*** range was utilized to categorize them as either fixed or gliding points.
- Fixed Points: 8.3 mm + .5 mm / - .29 mm (8.01 mm to 8.8 mm)
- Gliding Points: 11 mm +/- .5 mm (10.5 mm to 11.5 mm)
- Indeterminate (in-between or unknown): 9.65 mm +/- .75 (8.9 mm to 10.4 mm)

Hole Measurements



Categorization of Holes

of Fixed Points: 0

# of Gliding Points: 0

# of Indeterminate: 12

Summary of Measurements

$Average_{Indeterminate}$: 9.6 mm

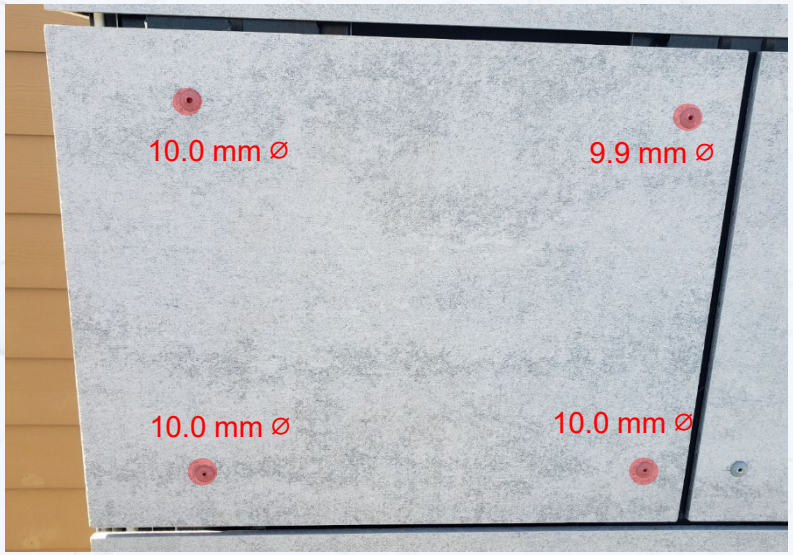
$Maximum_{Indeterminate}$: 9.7 mm

$Minimum_{Indeterminate}$: 9.4 mm

Legend Reference

- Fixed Points: 8.3 mm + .5 mm / - .29 mm (8.01 mm to 8.8 mm)
- Gliding Points: 11 mm +/- .5 mm (10.5 mm to 11.5 mm)
- Indeterminate: 9.65 mm +/- .75 (8.9 mm to 10.4 mm)

Hole Measurements



Categorization of Holes

of Fixed Points: 0

# of Gliding Points: 0

# of Indeterminate: 4

Summary of Measurements

$Average_{Indeterminate}$: 10.0 mm

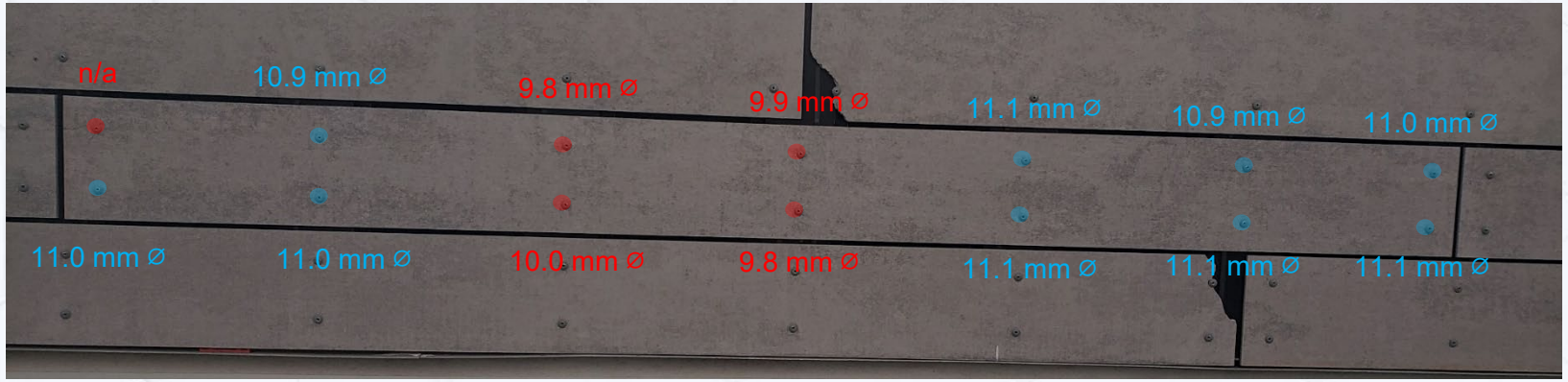
$Maximum_{Indeterminate}$: 10.0 mm

$Minimum_{Indeterminate}$: 9.9 mm

Legend Reference

- Fixed Points: 8.3 mm + .5 mm / - .29 mm (8.01 mm to 8.8 mm)
- Gliding Points: 11 mm +/- .5 mm (10.5 mm to 11.5 mm)
- Indeterminate: 9.65 mm +/- .75 (8.9 mm to 10.4 mm)

Hole Measurements



Legend Reference

- Fixed Points: 8.3 mm + .5 mm / - .29 mm (8.01 mm to 8.8 mm)
- Gliding Points: 11 mm +/- .5 mm (10.5 mm to 11.5 mm)
- Indeterminate: 9.65 mm +/- .75 (8.9 mm to 10.4 mm)

Categorization of Holes

of Fixed Points: 0

# of Gliding Points: 9

# of Indeterminate: 5

Summary of Measurements

$Average_{Gliding}$: 11.0 mm

$Maximum_{Gliding}$: 11.1 mm

$Minimum_{Gliding}$: 10.9 mm

$Average_{Indeterminate}$: 9.9 mm

$Maximum_{Indeterminate}$: 10.0 mm

$Minimum_{Indeterminate}$: 9.8 mm

Hole Measurements

Legend Reference

- Fixed Points: 8.3 mm + .5 mm / - .29 mm (8.01 mm to 8.8 mm)
- Gliding Points: 11 mm +/- .5 mm (10.5 mm to 11.5 mm)
- Indeterminate: 9.65 mm +/- .75 (8.9 mm to 10.4 mm)

Categorization of Holes

of Fixed Points: 0

# of Gliding Points: 8

# of Indeterminate: 6

Summary of Measurements

$Average_{Gliding}$: 11.0 mm

$Maximum_{Gliding}$: 11.1 mm

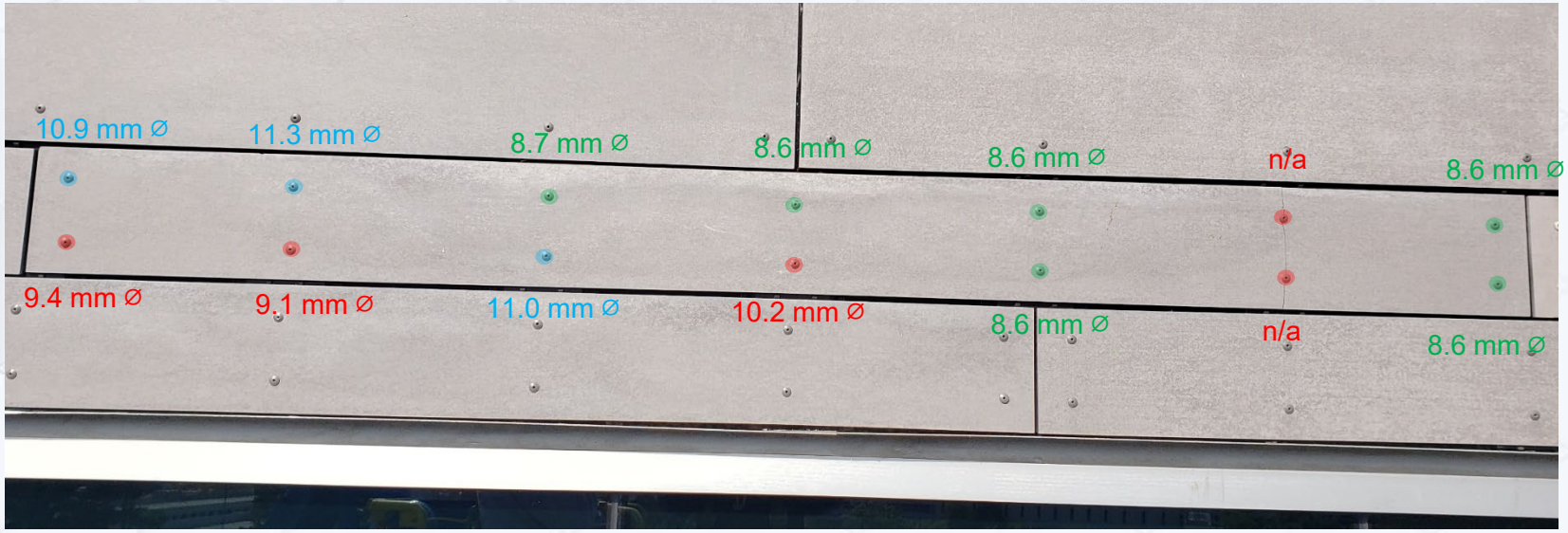
$Minimum_{Gliding}$: 10.6 mm

$Average_{Indeterminate}$: 9.9 mm

$Maximum_{Indeterminate}$: 10.3 mm

$Minimum_{Indeterminate}$: 9.6 mm

Hole Measurements



Legend Reference

- Fixed Points: 8.3 mm + .5 mm / - .29 mm (8.01 mm to 8.8 mm)
- Gliding Points: 11 mm +/- .5 mm (10.5 mm to 11.5 mm)
- Indeterminate: 9.65 mm +/- .75 (8.9 mm to 10.4 mm)

Categorization of Holes

of Fixed Points: 6

# of Gliding Points: 3

# of Indeterminate: 5

Summary of Measurements

$Average_{Fixed}$: 8.6 mm

$Maximum_{Fixed}$: 8.7 mm

$Minimum_{Fixed}$: 8.6 mm

$Average_{Gliding}$: 11.0 mm

$Maximum_{Gliding}$: 11.3 mm

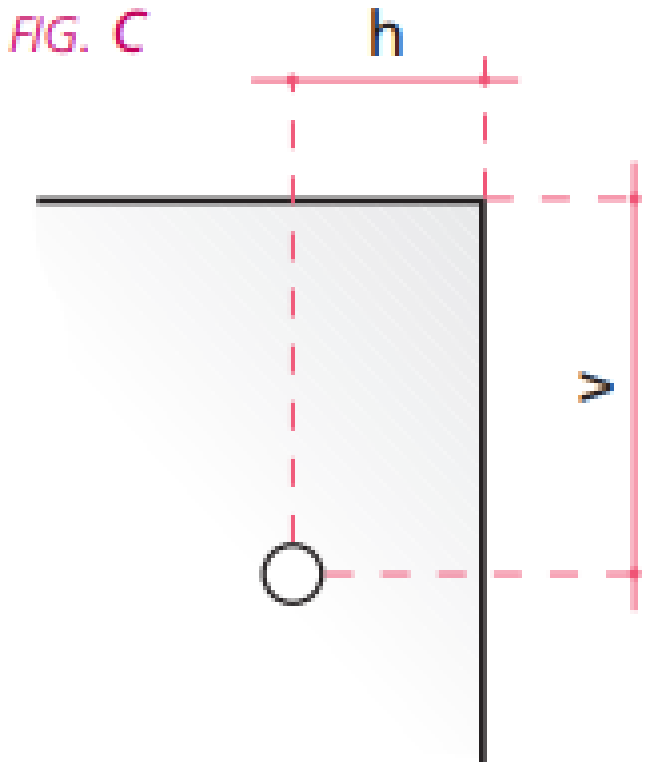
$Minimum_{Gliding}$: 10.9 mm

$Average_{Indeterminate}$: 9.6 mm

$Maximum_{Indeterminate}$: 10.2 mm

$Minimum_{Indeterminate}$: 9.1 mm

Edge Spacing Requirements



	mm	(in.)
h:	40–150	(1 9/16–5 7/8)
v:	70–150	(2 3/4–5 7/8)

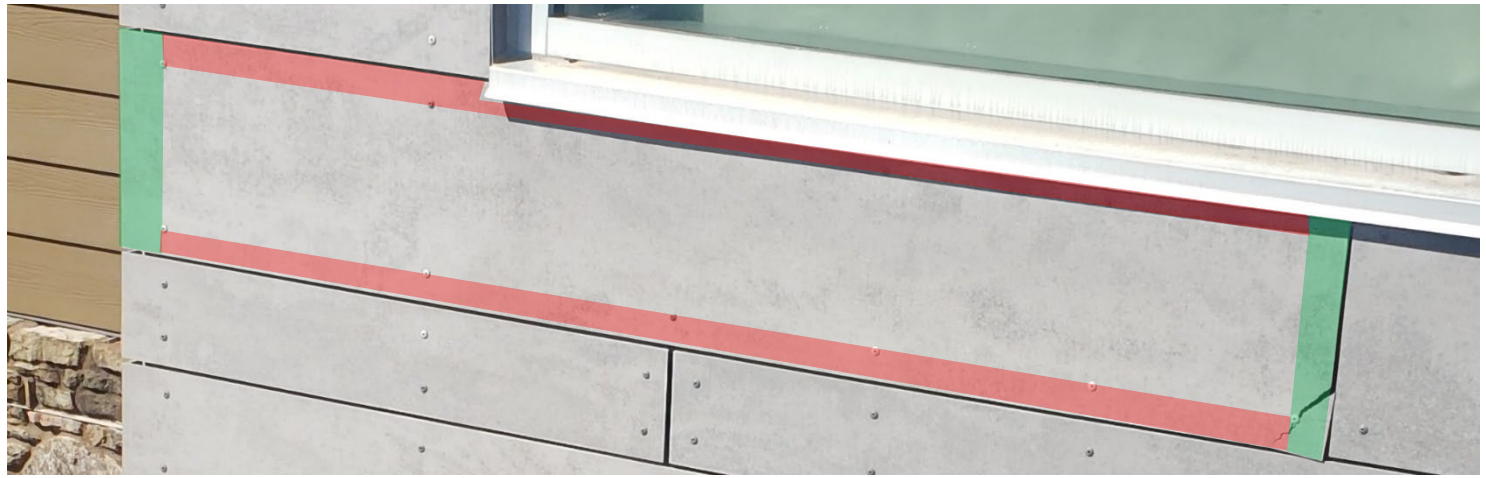
Corner rivets to be located at 40 – 150 mm horizontally and 70 – 150 mm down/up vertically from each corner of panel. (*FIG.* **C**)

Edge Spacing Measurements

Categorization of Field Measurements

- For measurements that fell outside the specified range, an ***arbitrary*** range was utilized to describe the relative severity out of tolerance.
- Compliant: Satisfies manufacturer's installation guidelines.
- Marginally Non-Compliant: Exceed installation guidelines by ≤ 1/2".
- Excessively Non-Compliant: Exceed installation guidelines by > 1/2".

Edge Spacing Measurements



Summary of Measurements

h_{left}: 3-7/8”

h_{right}: 2-1/8”

v_{top}: 2”

v_{bottom}: 2”

Categorization of Edge Spacing

Compliant: 2

Marginally Non-Compliant: 0

Excessively Non-Compliant: 2

Legend Reference

	mm	(in.)
h:	40–150	(1 9/16–5 7/8)
v:	70–150	(2 3/4–5 7/8)

Marginally Non-Compliant

(1-1/16” to 1-1/2”; 5-15/16” to 6-3/8”)

(2-1/4” to 2-11/16”; 5-15/16” to 6-3/8”)

Excessively Non-Compliant

(< 1-1/16”; > 6-3/8”)

(< 2-1/4”; > 6-3/8”)

Edge Spacing Measurements

Summary of Measurements

h_{left}: 3-7/8”

h_{right}: 1-1/2”

v_{top}: 2”

v_{bottom}: 2”

Categorization of Edge Spacing

Compliant: 1

Marginally Non-Compliant: 1

Excessively Non-Compliant: 2

Legend Reference

	mm	(in.)
h:	40–150	(1 9/16–5 7/8)
v:	70–150	(2 3/4–5 7/8)

Marginally Non-Compliant

(1-1/16” to 1-1/2”; 5-15/16” to 6-3/8”)

(2-1/4” to 2-11/16”; 5-15/16” to 6-3/8”)

Excessively Non-Compliant

(< 1-1/16”; > 6-3/8”)

(< 2-1/4”; > 6-3/8”)

Edge Spacing Measurements

Summary of Measurements

h_{left}: 2”

h_{right}: 2”

v_{top}: 2”

v_{bottom}: 2”

Categorization of Edge Spacing

Compliant: 2

Marginally Non-Compliant: 0

Excessively Non-Compliant: 2

Legend Reference

	mm	(in.)
h:	40–150	(1 9/16–5 7/8)
v:	70–150	(2 3/4–5 7/8)

Marginally Non-Compliant

(1-1/16” to 1-1/2”; 5-15/16” to 6-3/8”)

(2-1/4” to 2-11/16”; 5-15/16” to 6-3/8”)

Excessively Non-Compliant

(< 1-1/16”; > 6-3/8”)

(< 2-1/4”; > 6-3/8”)

Edge Spacing Measurements

Summary of Measurements

h_{left}: 2”

h_{right}: 2”

v_{top}: 2”

v_{bottom}: 2”

Categorization of Edge Spacing

Compliant: 2

Marginally Non-Compliant: 0

Excessively Non-Compliant: 2

Legend Reference

	mm	(in.)
h:	40–150	(1 9/16–5 7/8)
v:	70–150	(2 3/4–5 7/8)

Marginally Non-Compliant
(1-1/16” to 1-1/2”; 5-15/16” to 6-3/8”)
(2-1/4” to 2-11/16”; 5-15/16” to 6-3/8”)

Excessively Non-Compliant
(< 1-1/16”; > 6-3/8”)
(< 2-1/4”; > 6-3/8”)

Edge Spacing Measurements

Summary of Measurements

h_{left}: 2”

h_{right}: 2”

v_{top}: 2”

v_{bottom}: 2”

Categorization of Edge Spacing

Compliant: 2

Marginally Non-Compliant: 0

Excessively Non-Compliant: 2

Legend Reference

	mm	(in.)
h:	40–150	(1 9/16–5 7/8)
v:	70–150	(2 3/4–5 7/8)

Marginally Non-Compliant

(1-1/16” to 1-1/2”; 5-15/16” to 6-3/8”)

(2-1/4” to 2-11/16”; 5-15/16” to 6-3/8”)

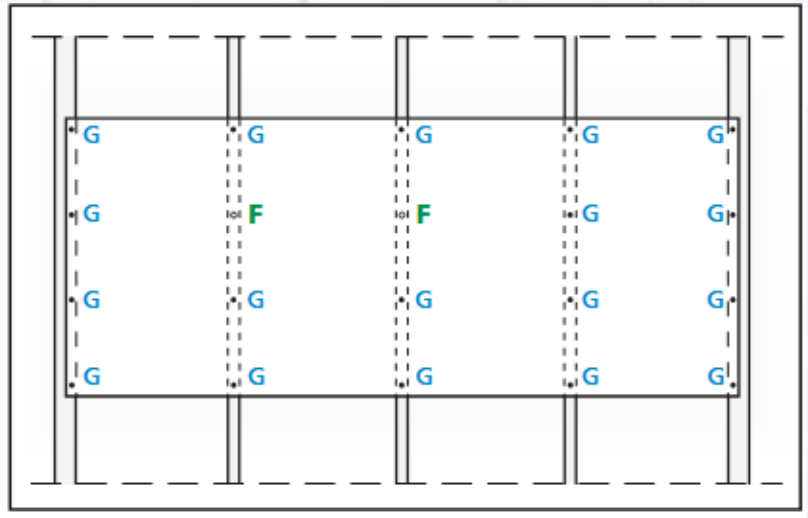
Excessively Non-Compliant

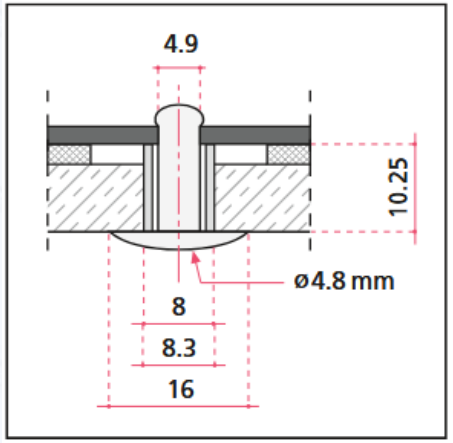
(< 1-1/16”; > 6-3/8”)

(< 2-1/4”; > 6-3/8”)

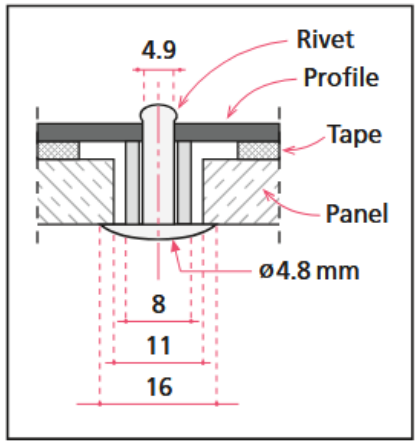
Failure Analysis

- Hole locations/diameters not per manufacturer installation guidelines.



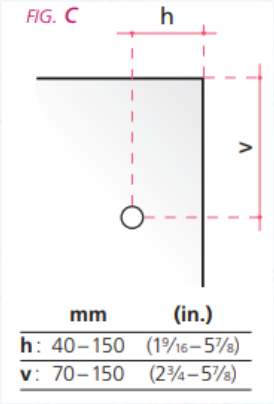


Fixed Point *— cylinder & rivet*



Gliding Point *— cylinder & rivet*

- Edge spacing not per manufacturer installation guidelines.



QUESTION & ANSWER PERIOD

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Speaker & Presentation Evaluation

Cracking Under Pressure