

# Special Inspections for Externally Applied FRP: How Much is Enough?

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# FRP Special Inspections

## Why even talk about this stuff?

- Because FRP Special Inspections are expensive....sometimes having the potential to double the cost of FRP installations.
- Because every project has a budget, and inspection costs have to figure into that budget.
- Because the EOR will be challenged by the Owner to reduce the cost of inspections.
- To effectively respond to the challenge, the EOR needs to know which tests are the most useful and what quantity is enough.

# FRP Special Inspections

As a basis for this presentation, our office has assembled data on field tests and inspections from thousands of installations. The data represents:

- A variety of products by several different manufacturers.
- Installation procedures using wet layup, dry layup, precured laminate and NSM bars.
- Work performed by a variety of specialty contractors.
- Indoor and outdoor applications
- Strengthening, repair, and renovation projects

# FRP Special Inspections

Limitations on the data include:

- Regional: most projects are in the Texas and southwest region.
- Despite the volume, the data represents just a small sampling of work across the US.

Even with these limitations, we believe the data is representative of work performed around the country. Most of the manufacturers and contractors in this sample perform similar work throughout the US.

# When Training for a Marathon, Every Training Run Should have a Purpose.



# In Construction, Every Test and Inspection Should Have a Purpose.

- General: To gain assurance that the FRP has been effectively applied.
- How is this done:
  - Manufacturer certifications of material properties
  - Laboratory testing of Witness Panels
  - Field testing with Pull-off tests (adhesion testing)
  - Field inspections of installation

# Materials Testing

- The purpose is to assure that the materials used meet project specifications
- Two basic methods used:
  - ACI 440.2 states that Manufacturer's Certifications should be submitted for review and conformance to project specifications.
  - ACI 440.2 allows the use of Witness Panels to evaluate the FRP system installed on site.
  - Additional material testing can be conducted on complicated and intricate projects.

# Witness Panels

- Also known as coupon tests: Per ACI 440.2, used to “evaluate tensile strength and modulus, lap splice strength, hardness and Tg of the FRP system...”
- Witness panels are flat panels fabricated on site using installation procedures similar to those used to install and cure the FRP system.
- After curing they are sent to a laboratory for testing.
- Testing methods should follow ACI 440.3R, Test Method L.2.





# Witness Panels

- Frequency of Tests: ACI 440.2 allows the use of witness panels and states that the licensed professional “may waive or alter the frequency of testing.” In other words...engineering judgement is required.
- Commonly used frequencies:
  - Small projects: 1 panel for each new roll of material or for each new batch of epoxy or 1 per day. Randomly select 15% to be sent to the lab for testing.
  - Large projects: 1 panel for each new roll of material or for each new batch of epoxy or 3 per area. Randomly select 10% to be sent to the lab for testing.

# Witness Panels

Rate of Passing: 100%



- This is a materials test on materials that have already passed the manufacturer's testing and certification program.
- Materials have been manufactured in a controlled environment, tested for quality and sold to repeat customers....The manufacturer has a stake in getting it right....

# Field Pull-Off Tests

- Also known as Bond Tests or Adhesion Tests: Tests performed to insure adequate bond has been achieved between FRP and the concrete substrate.
- Per ACI 440.2, these should be conducted using the methods in ASTM D4541, or ACI 503R or ACI 440.3R, Test Method L.1.



# Field Pull-Off Tests

Perfectly position lift so inspector fits between obstacles.



Rent lift.

Build slope specific ramp



# Field Pull-Off Tests

Perfectly position  
lift so inspector fits  
between obstacles.



# Field Pull-Off Tests

Perfectly position  
lift so inspector fits  
between obstacles.





# Field Pull-Off Tests

Score around  
pucks



# Field Pull-Off Tests

Repeat this process for each and every field pull-off test.

Pull pucks from test panel





# Field Pull-Off Tests

- Frequency: ACI 440.2 requires the frequency of tests to be specified by the licensed professional: Engineering judgement is required.
  - Common Frequencies:
    - 1 test panel / area / day / material type
- What is the limiting factor that determines the frequency?

# Field Pull-Off Tests

- How does the definition of area affect the frequency?
  - Compare two recent projects:
    - Project A: 2 bay x 2 bay = approximately 3,600 s.f.
    - Project B: 6 bay x 3 bay = approximately 16,200 s.f.
  - Did Project A have a higher frequency rate?

# Field Pull-Off Tests

- Actual limiting factor was how much work the contractor could perform in one day.
  - Contractor averaged 40 installations per day, with a max of 63 per day.
  - Both projects received approximately same ratio of installations per test.
  - Size of area generally does not control frequency. Practical limits on rates of installation generally control frequency.

# Field Pull-Off Tests

- How can the licensed professional gain control over the frequency?
- If critical, add the following: “or a minimum of one test panel per “xx” installations.”
  - Ex.: 1 test panel / area / day / material, or a minimum of 1 test panel per 75 installations.

# Field Pull-Off Tests

- What is a comparable test used in conventional concrete construction?
- Concrete strength testing with cylinders:
  - With both FRP and Concrete, the individual materials have been tested and certified.
  - With both, the test is intended to determine the strength of the combined materials.
  - Both are field tests with the intention of determining the adequacy of the field installation.

# Field Pull-Off Tests

With one major difference:

- Samples for concrete strength tests are to be taken on a strictly random basis.
- Test panels for FRP bond tests are predetermined by the contractor.
- It is human nature to put forth extra effort when being tested.



# Field Pull-Off Tests

Rate of Passing: 99%

That's Great! – Right?

- Except that sometimes when things appear too good to be true, they actually are too good to be true.

# Field Pull-Off Tests

- Is this an issue?

In the photo at right, the pull test passed.

And yet, a human hand can be inserted between the fabric and the concrete.

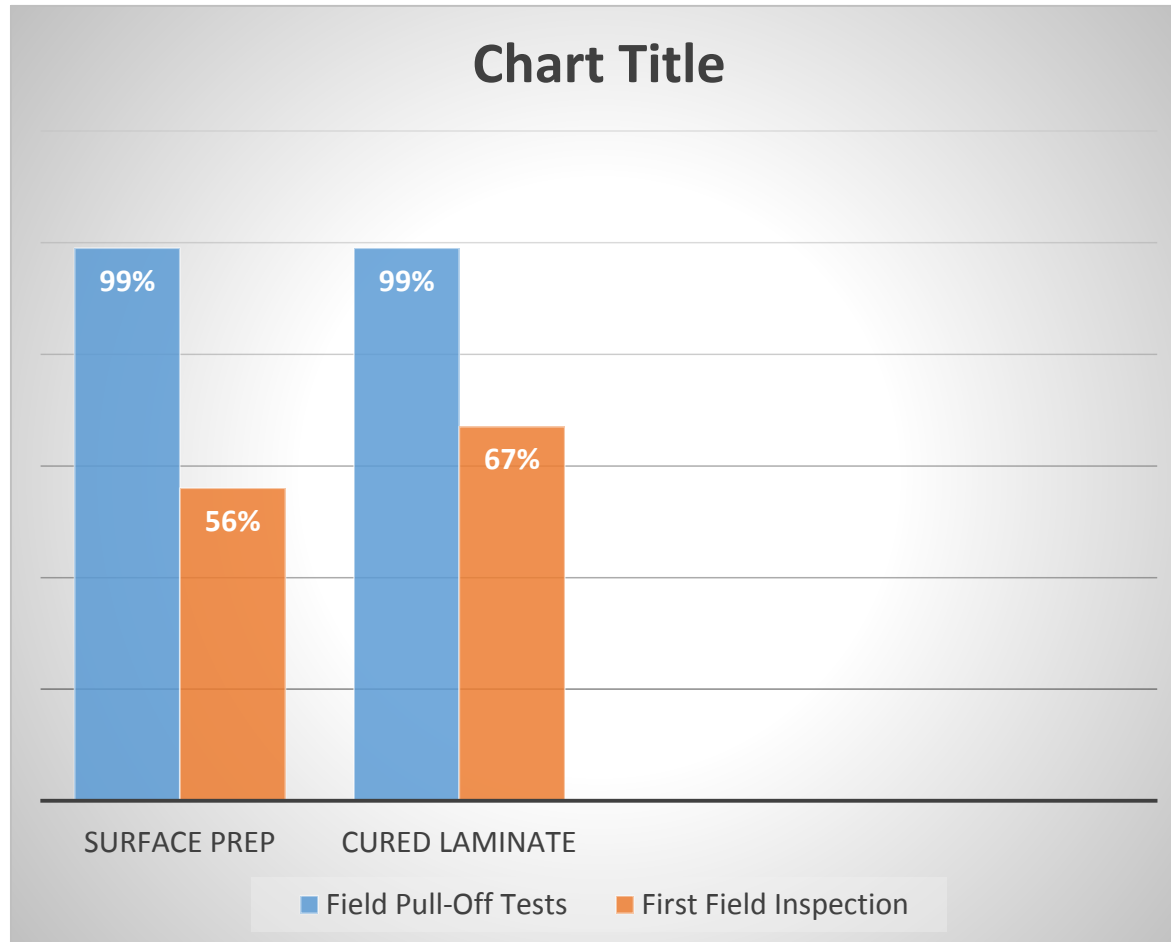
This is an extreme condition, but helps to illustrate that heavy reliance on pull test data could be ill founded.

As further illustration, we did a pull test on the side walls of this U wrap and the test results were acceptable.





# Field Pull-Off Tests



- Pass rates for surface preparation and cured laminate do not come close to the success rate of pull tests.
  - Surface Prep: Pass rate on first inspection..... 56%
  - Cured Laminate: Pass rate on first inspection.....67%
- Lets take a look at those inspections.

# Surface Prep Inspections

- What: These are visual inspections that should confirm the following:
  - Correct location



# Surface Prep Inspections

- What: These are visual inspections that should confirm the following:
  - Sufficient surface profile based on comparison to ICRI Surface Profile Chips



# Surface Prep Inspections

- What: These are visual inspections that should confirm the following:
  - Injection of significant cracks





# Surface Prep Inspections

- What: These are visual inspections that should confirm the following:
  - Patching of voids and rounding of sharp corners



# Surface Prep Inspections

- What: These are visual inspections that should confirm the following:
  - Cleanliness



# Surface Prep Inspections

- What: These are visual inspections that should confirm the following:
  - Correct handling of foreign objects and embedded items that conflict with installation.



# Surface Prep Inspections

- What: These are visual inspections that should confirm the following:
  - Correct location
  - Sufficient surface profile based on comparison to ICRI Surface Profile Chips
  - Injection of significant cracks
  - Patching of voids and rounding of sharp corners
  - Cleanliness
  - Correct handling of foreign objects and embedded items that conflict with installation.
- Frequency: Per ACI 440.2, these should be conducted daily. This is generally interpreted as inspecting 100% of the installations.

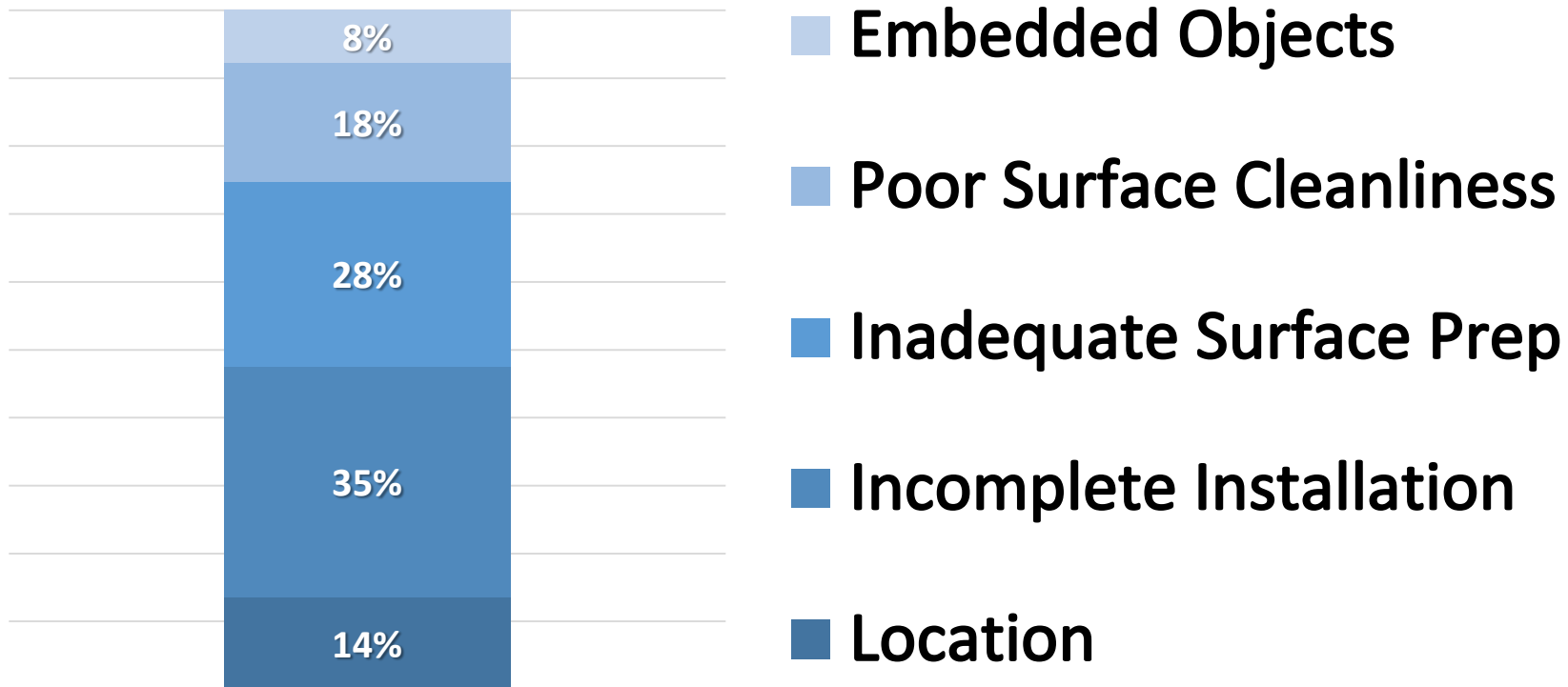


# Surface Prep Inspections

- Rate of Passing:
  - 56% Pass on first inspection
  - 20% Require three or more inspections
  - Average: 1.8 inspections per installation
- Why is this pass rate so low? What specifically is failing?

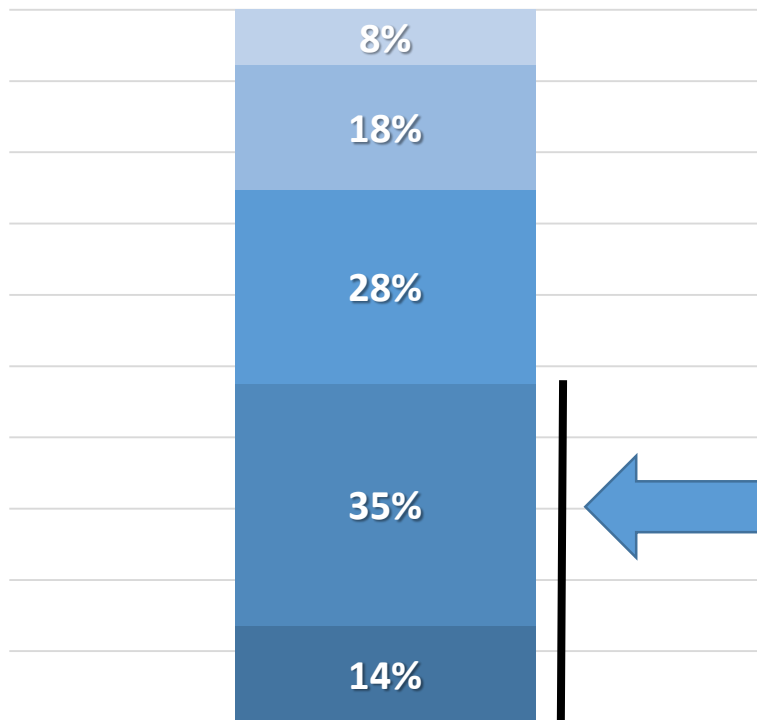
# Surface Prep Inspections

## Most Common Reasons for Failed Inspections



# Surface Prep Inspections

## Most Common Reasons for Failed Inspections



49% of failures are of the most basic type; failure to properly locate and complete the entire prep area.

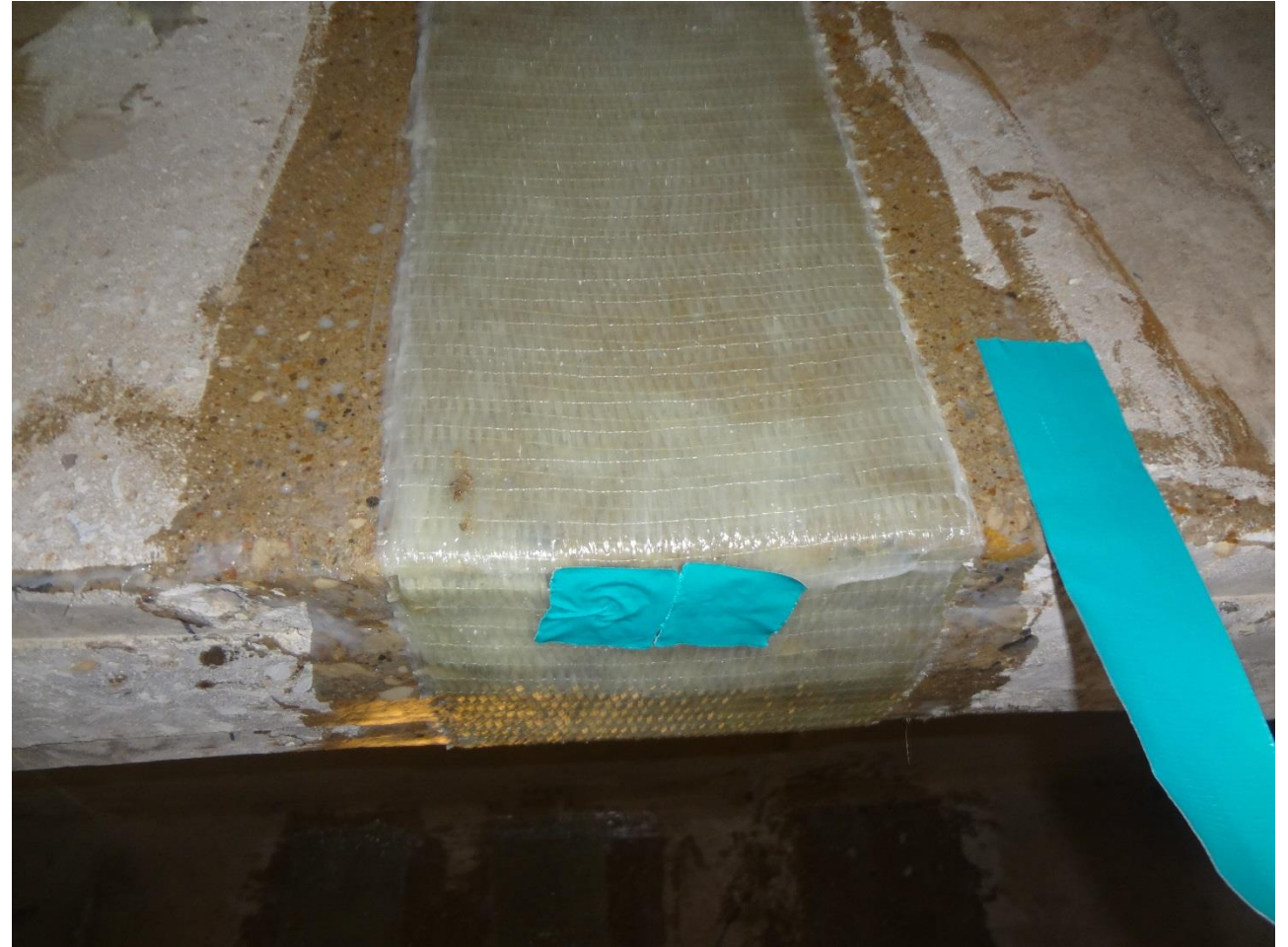
# Cured Laminate Inspections

- What: These are visual inspections with acoustical sounding that should identify and determine acceptability of the following:
  - Location and dimensions of wrap
  - Completeness of installation including number of plies



# Cured Laminate Inspections

- What: These are visual inspections with acoustical sounding that should identify and determine acceptability of the following:
  - Locations, sizes and groupings of delaminations or voids
  - Saturation
  - Fabric Orientation



# Cured Laminate Inspections

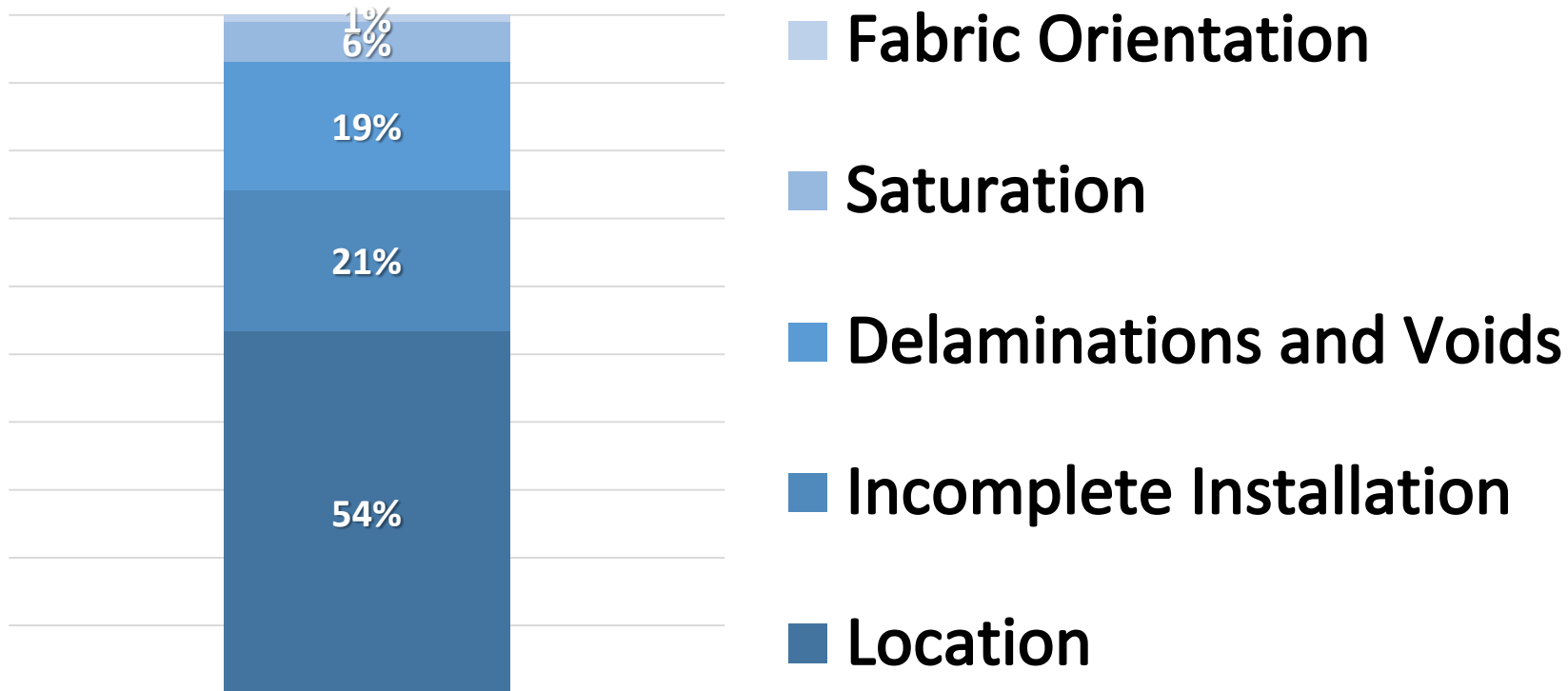
- What: These are visual inspections with acoustical sounding that should identify and determine acceptability of the following:
  - Location and dimensions of wrap
  - Completeness of installation including number of plies
  - Locations, sizes and groupings of delaminations or voids
  - Saturation
  - Fabric Orientation
- Frequency: Per ACI 440.2, these should be conducted daily. This is generally interpreted as inspecting 100% of the installations.

# Cured Laminate Inspections

- Rate of Passing:
  - 67% Pass on first inspection
  - 12% Require three or more inspections
  - Average: 1.5 inspections per installation
- What are the specific reasons for failures?

# Cured Laminate Inspections

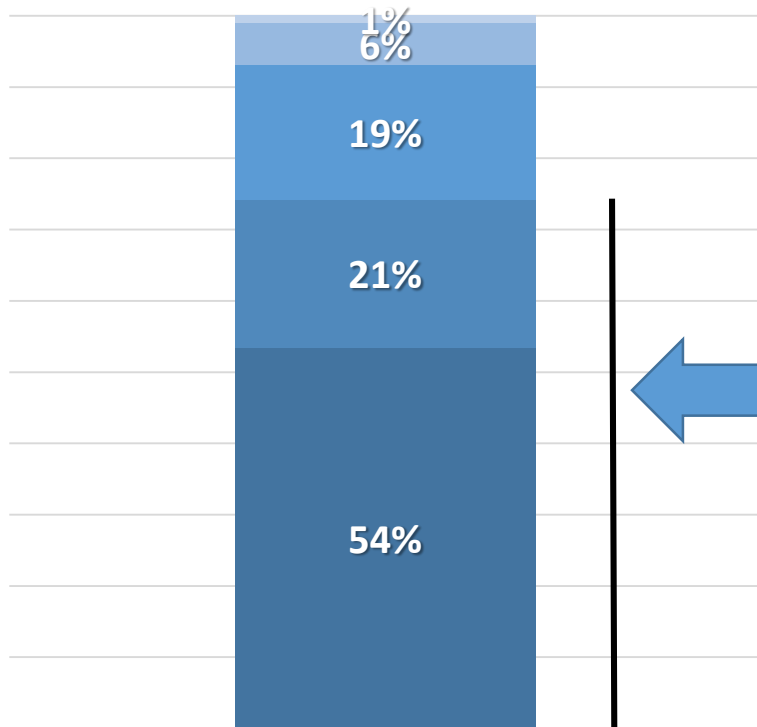
## Most Common Reasons for Failed Inspections





# Cured Laminate Inspections

## Most Common Reasons for Failed Inspections



75% of failures are of the most basic type; failure to properly locate and complete the installation.

# Why are Field Inspections and Controlled Testing Results so Different?



Lab Installation

Field Installation



# Why are Field Inspections and Controlled Testing Results so Different?



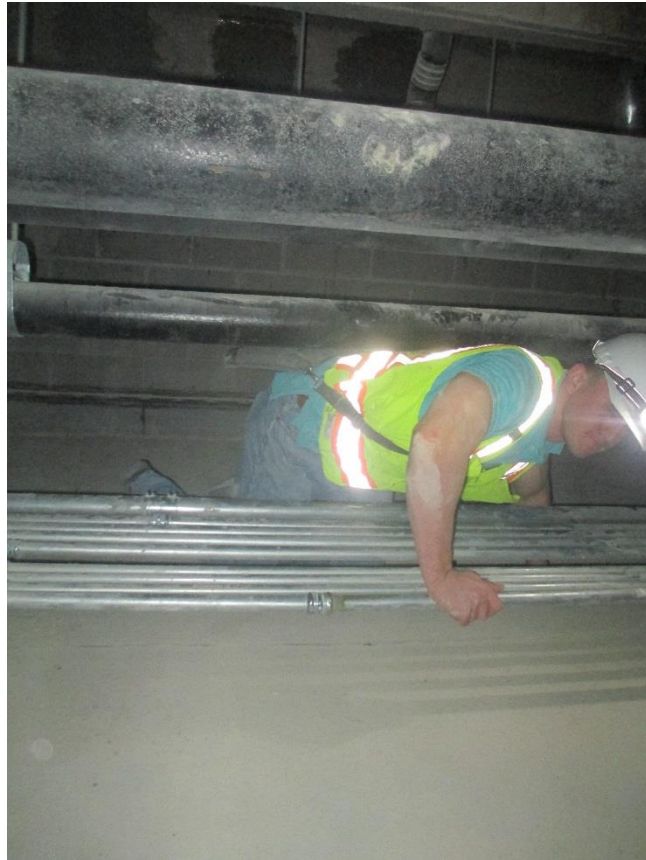
Lab Conditions - Cleanliness

Field Conditions - Cleanliness





# Why are Field Inspections and Controlled Testing Results so Different?



Difficulty of Access

# Why are Field Inspections and Controlled Testing Results so Different?



Difficulty of Access



# Why are Field Inspections and Controlled Testing Results so Different?



Difficulty of Access

# So How Much is Enough?

- How can we apply this information to a project specific special inspection plan?
- Quality assurance of Materials
  - Manufacturer certifications are mandatory and won't add to the project budget.
  - Witness panels are a useful tool, but are sometimes over used.
    - Testing of witness panels is relatively expensive.
    - Tests have a high rate of passing because they are re-testing materials that have already passed the manufacturer's certification program.
    - The cost of each test is equivalent to the cost of 8-12 hours of field inspection....roughly 50 surface prep locations or 70 cured laminate inspections.

# So How Much is Enough?

- Quality assurance of installation:
  - Field pull-off tests are useful and should be specified, but frequency of testing should be carefully considered.
    - Field pull-off tests have a high pass rate.
    - Because the test is not randomized, and does not test the actual installation, reliance on test results can be misleading.
    - Costs of field pull-off tests are generally equivalent to the cost of 2-3 hours of field inspection or approximately 10-15 surface prep locations or 15-20 cured laminate inspections.



# So How Much is Enough?

- Quality assurance of installation:
  - Surface prep inspections:
    - Most failures are very basic in nature and require no special equipment – inspect for proper location and completeness of prep area. This is crucial. It represents 49% of all failures. This is similar to inspecting all reinforcing steel to assure proper placement.

# So How Much is Enough?

- Quality assurance of installation:
  - Cured Laminate Inspection: We consider this the most crucial and valuable inspection.
    - An experienced, well trained inspector can derive a lot of information during a cured laminate inspection.
      - Several key functions of the surface prep inspection can be determined despite the fact that the surface has been covered by fabric. Location, completeness, crack injection, surface prep area, rounding of corners can all still be estimated with reasonable accuracy.
    - Visual inspection and sounding ascertains fiber orientation, voids, delaminations, and wrap dimensions, none of which are represented in pull- off tests.

# So How Much is Enough?

## Summary

- Most errors are basic and require only visual inspection to detect.
- Maximize time at the site performing visual inspections.
- Reduce the number of, and reliance on pull-off tests.
- Determine the necessity of witness panels and consider eliminating them, particularly on small projects.

# Special Inspections for Externally Applied FRP: How Much is Enough?

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