CONDITION ASSESSMENT OF FRP STRENGTHENING OF CONCRETE BRIDGE COMPONENTS

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Outline

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- Objectives
- Test Procedure
- Results and Discussion
- Conclusions and Recommendations
- Acknowledgement

Background Information

- According to ASCE 2013 report card:
  - **One in nine or 11 %** of the bridges are classified as structurally deficient.
  - **60,971** bridges have posted load restrictions.

- According to FHWA:
  - **More than 30%** of the existing bridges have exceeded their **50 years** design life.
  - **$20.5 billion** required to eliminate deficient bridges backlogs by **2028**, while only **$12.8 billion** is being spent currently.

Background Information

- According to USDOT out of 607,380 bridges in the nation:
  - **13.95% (84,748)** are functionally obsolete.
  - **10.98% (66,749)** are structurally deficient.

- Out of the **52,260** bridges in Texas:
  - **1,372 (2.6%)** are structurally deficient.
  - **8,680 (16.6%)** are considered functionally obsolete.

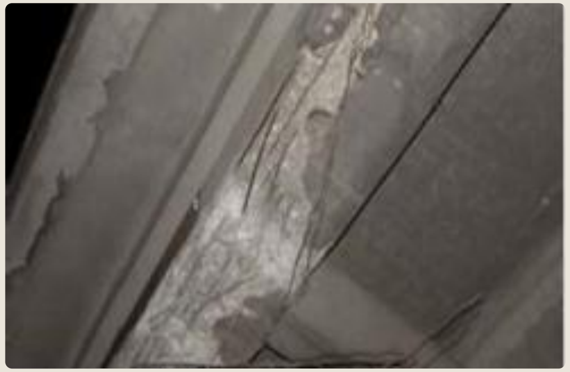
Background Information

- Repair and rehabilitation are generally economical, compared to rebuilding due to limited budget.
- Different strengthening techniques are available.
  - Externally bonded steel plate, steel/concrete jacketing, external post-tensioning and FRP wrapping.

Background Information

- FRP is a composite material made form of polymer (matrix) reinforced with fibers.
  - Fiber types: Glass, Carbon and Aramid.
  - Polymer (Matrix) types: Epoxy, Polyester and Vinyl Ester.
- FRP Wrap Advantages:
  - Ease of application, high strength-to-weight ratio, less labor intensive and corrosion resistant.
- FRP Wrap Disadvantages:
  - High material cost, lack of data on long term field performance, low fire resistance and limited experience.

FRP Strengthening Procedure



Damaged Girder

Splicing

Installing Pins

Retensioning

Pre-Loading

Sand Blasting

FRP Strengthening Procedure

Shotcreting

Epoxy Injection

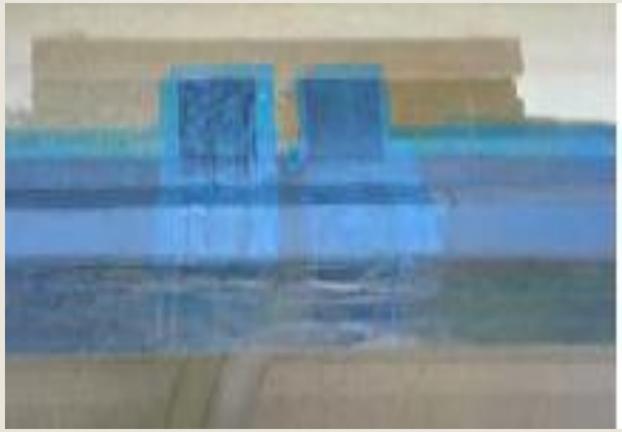
Application of Primer

Epoxy Application

1st Layer of FRP

2nd Layer of FRP

FRP Strengthening Procedure



Additional U-Wrap

Top coat Application

Completed Repair

- The effectiveness of FRP rehabilitation depends on the durability/quality of the bond between the FRP and concrete.
- This study evaluated the bond performance on several concrete bridges, owned by the Texas Department of Transportation (TxDOT), in the greater Dallas-Fort Worth (DFW) metroplex.

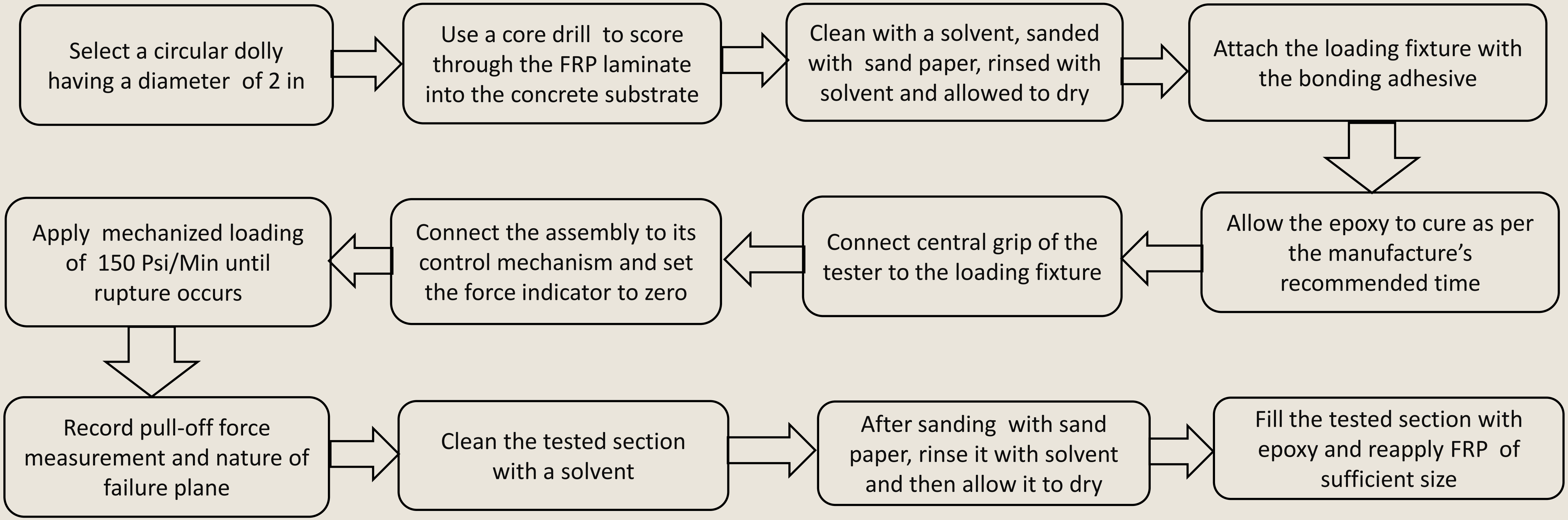
Objectives

- Visually inspect the in-service condition of the FRP strengthening for air pockets, delamination, debonding and FRP degradation.
- Evaluate the FRP bond condition using ASTM Pull-Off testing.
- Recommend quality control procedures for the initial FRP application and the Pull-Off testing to achieve better performance.

Test Procedures

- FRP-concrete bond can be evaluated using:
  - Non-destructive methods: acoustic sounding, chain dragging and thermographic imaging.
  - Destructive methods: differential scanning calorimetry and **ASTM Pull-Off test**.

Pull-Off Test Procedure



Pull-Off Test Procedure

(a) Core drilling

(b) Dolly attachment

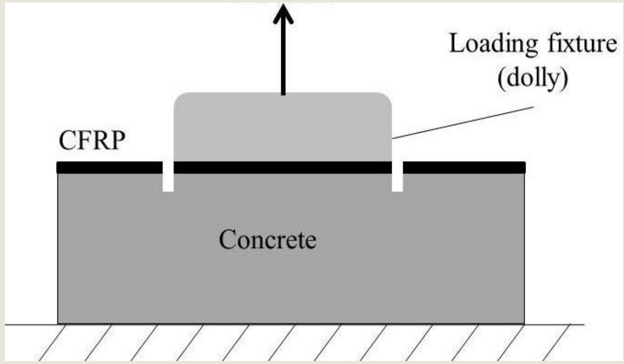
(c) Pull-off testing

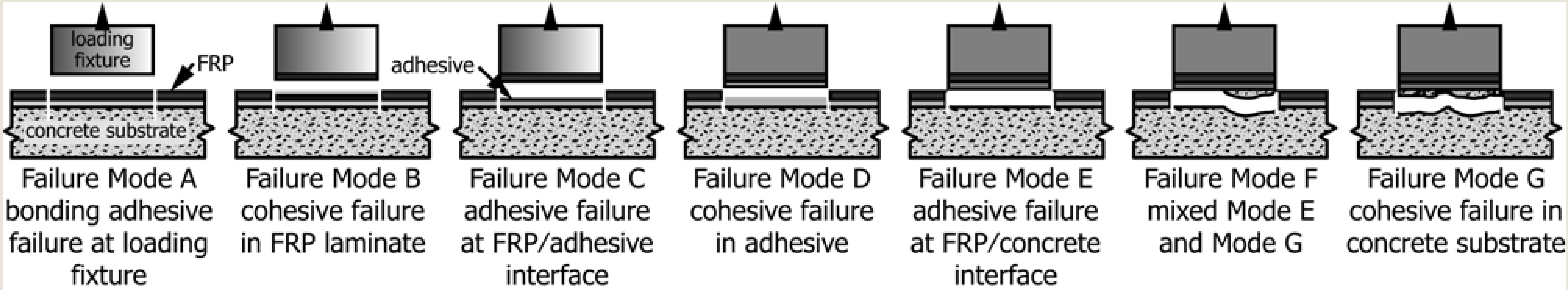
(d) Failed sample

(e) Load reading

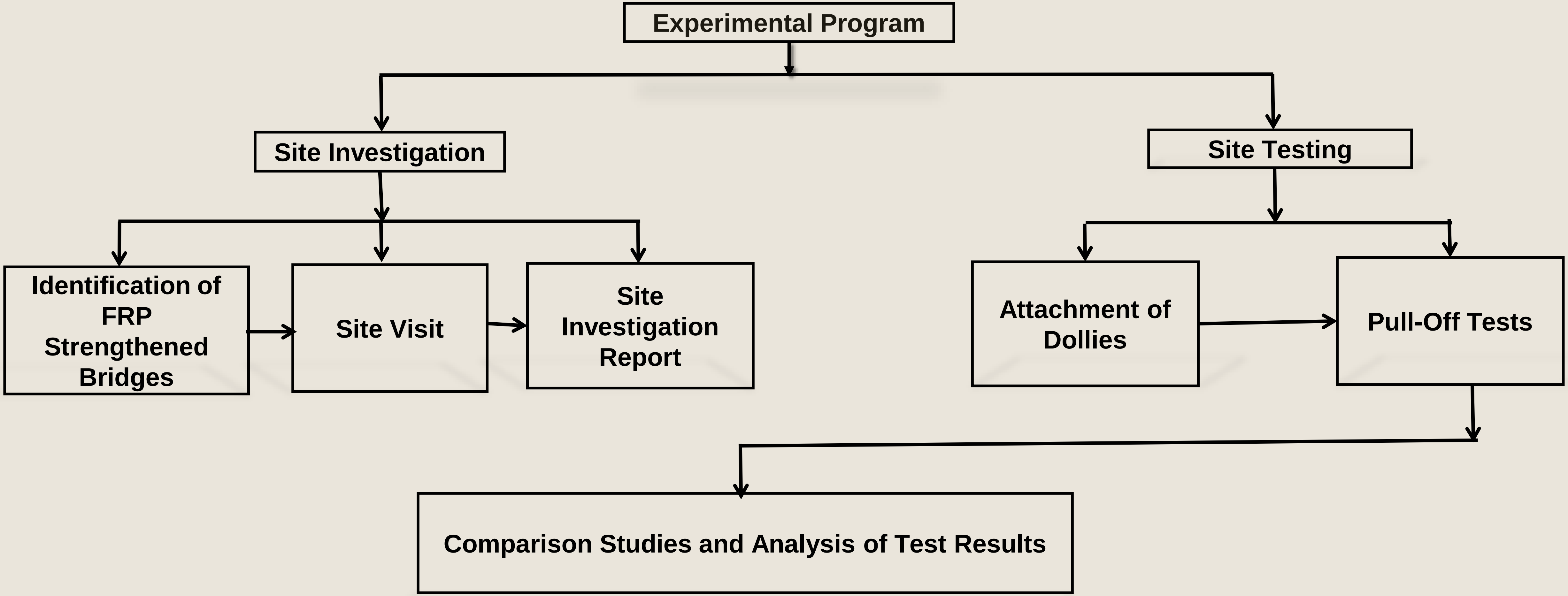
(f) Repaired surface

Pull-off Test Failure Modes





Study Procedure



Selected Bridge Information

Bridge No.	Location	Component Strengthened	Date of Inspection	Date of Pull-off Testing
1	SH 183 over Loop 12	Girder	05/28/2013	09/15/2013
2	LP 12 over Irving Blvd.	Girder	05/28/2013	09/15/2013
3	SH 183 over MacArthur Blvd.	Column and Girder	05/28/2013	09/15/2013
4	Gross Road over U.S. 80	Girder	05/28/2013	10/27/2013
5	Corinth St. over Trinity River	Pier Bent	05/28/2013	10/27/2013
6	Corinth Street over IH 35E	Girder	10/02/2013	10/27/2013
7	CR 470 over IH 20	Column	07/06/2013	12/19/2013
8	Loop 344 over SH 199	Girder	07/06/2013	12/19/2013

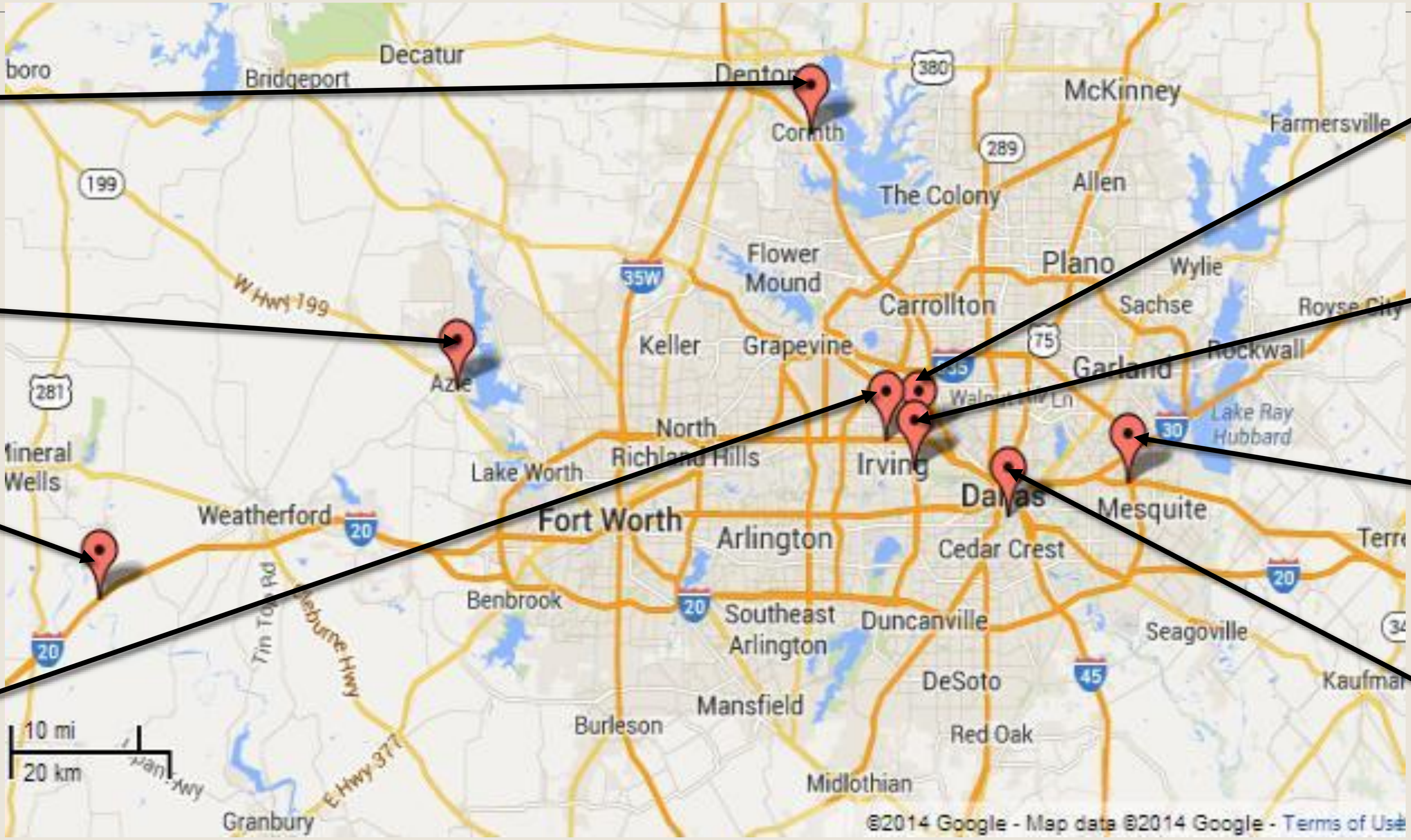
Bridge Locations

Bridge 6 (Corinth St. over IH 35E)

Bridge 8 (Loop 344 over SH 199)

Bridge 7 (CR 470 over IH 20)

Bridge 3 (SH 183 over MacArthur Blvd)



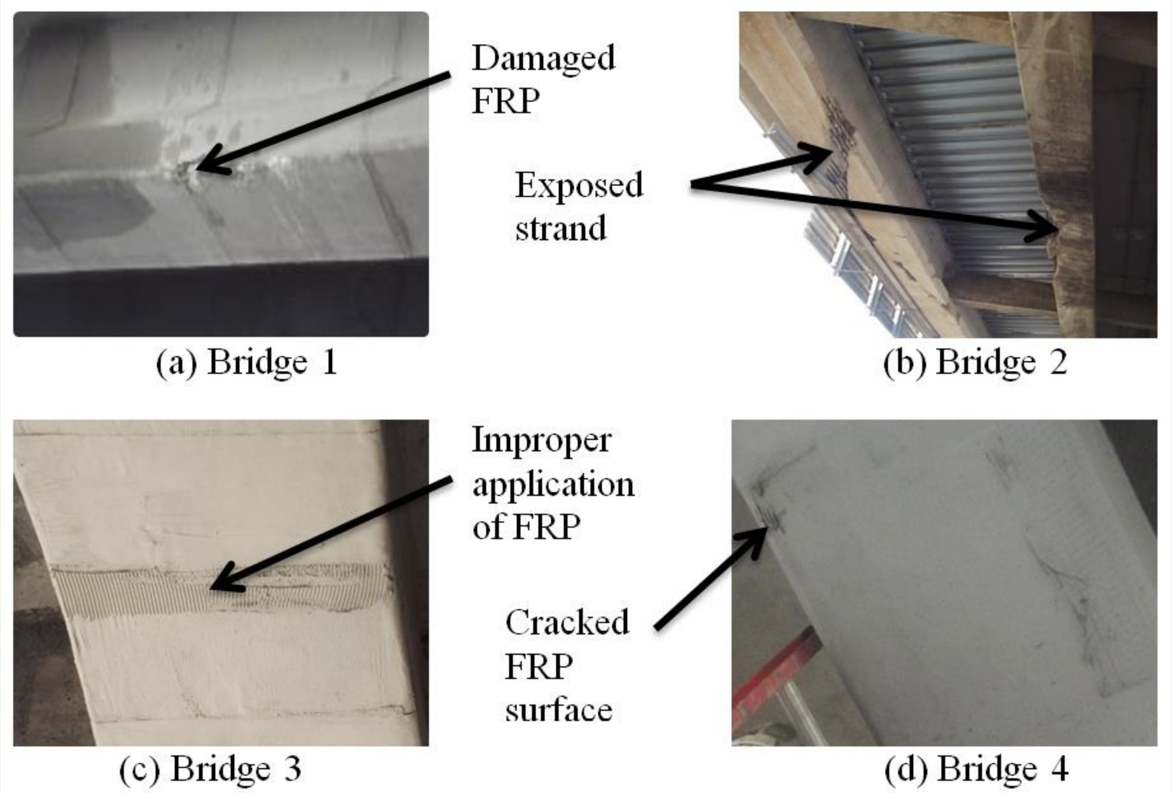
Bridge 1 (SH 183 over Loop 12)

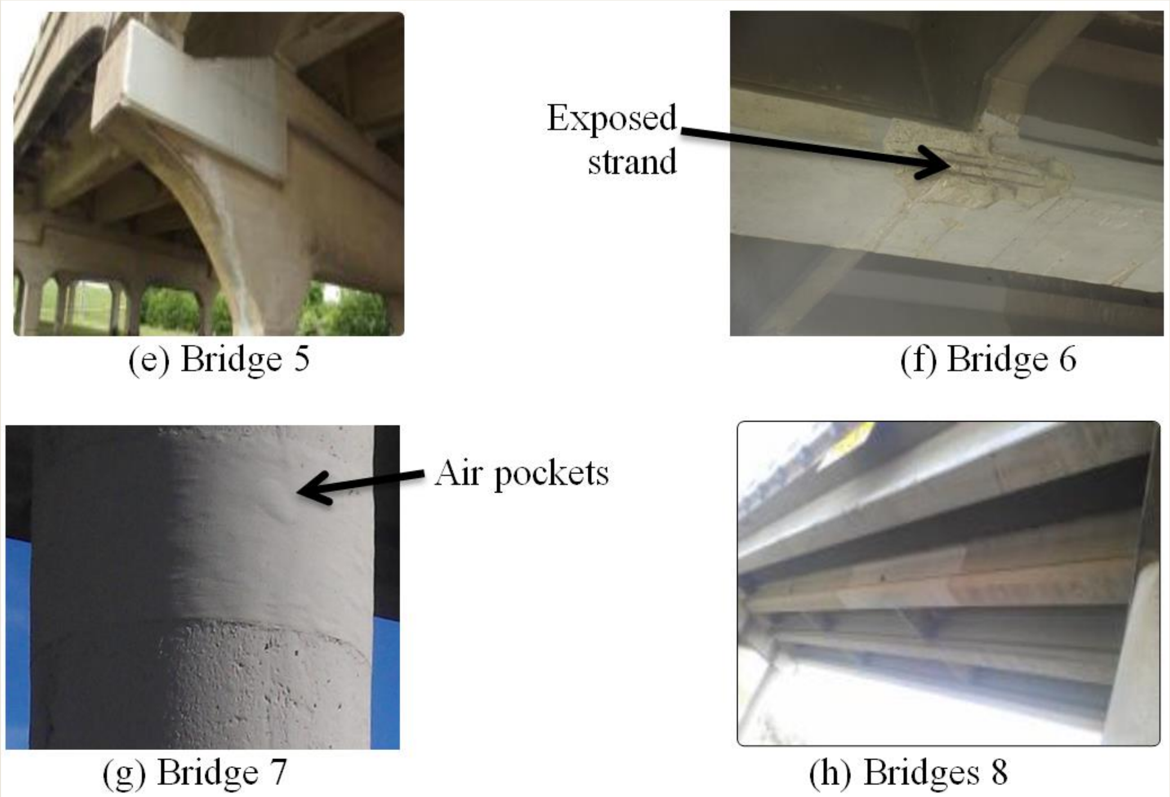
Bridge 2 (Loop 12 over Irving Blvd)

Bridge 4 (Gross Road over US 80)

Bridge 5 (Corinth St. over Trinity River)

Visual Inspection





Observed Failure Modes

Core Failure
Sample 4, B-1

Mode-A
Sample 2, B-1

Modes G &C
Sample 3, B-1

Mixed Mode M
Sample 5, B-1

Non-ASTM Mode

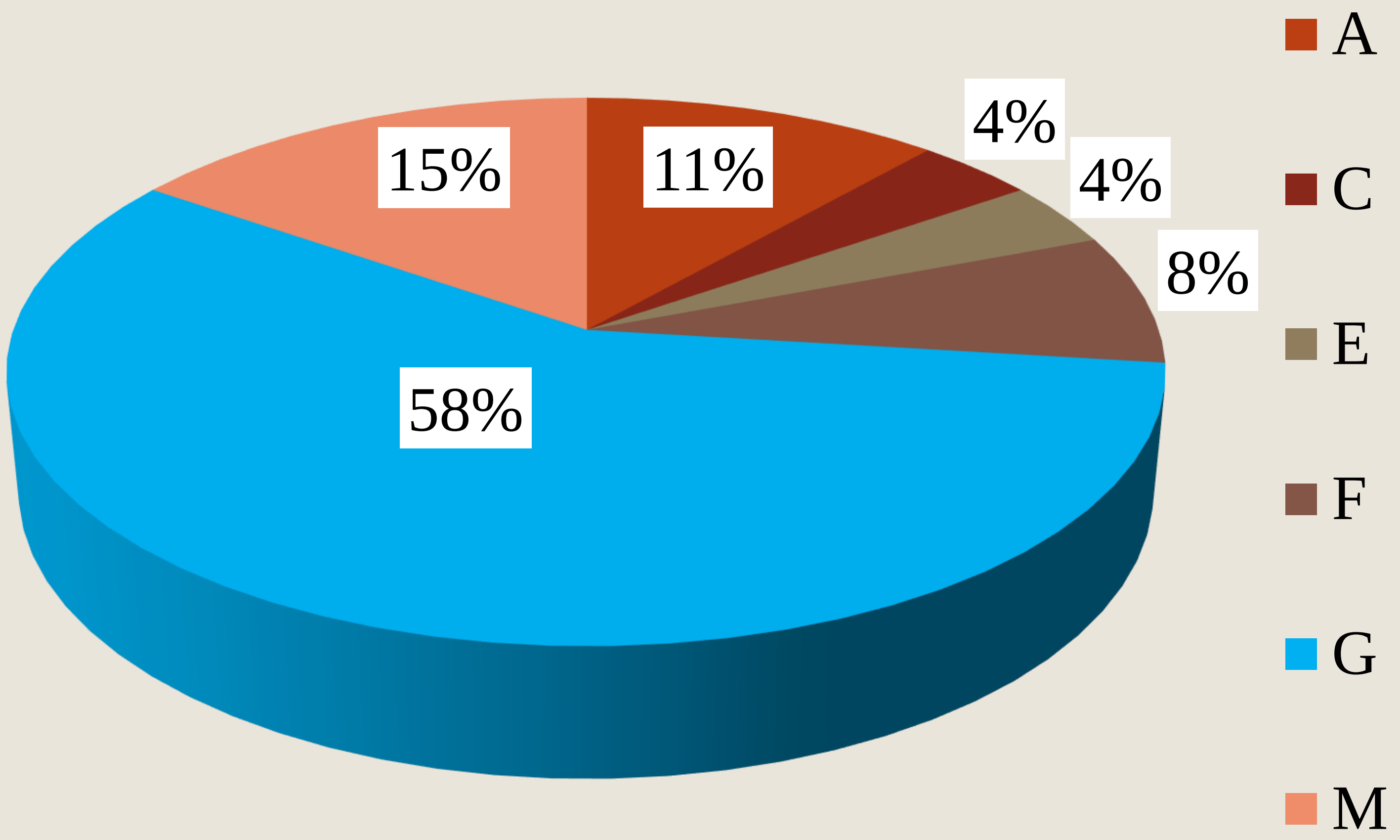
Mode-G
Sample 1, B-2

Mode-C
Sample 5, B-3

Mode-F
Sample 6, B-3

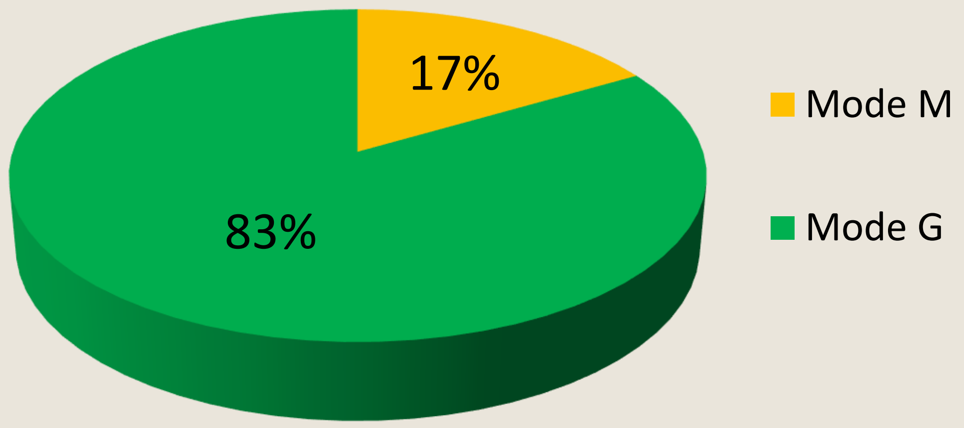
Mode-G
Sample 9, B-3

Summary of Failure Modes

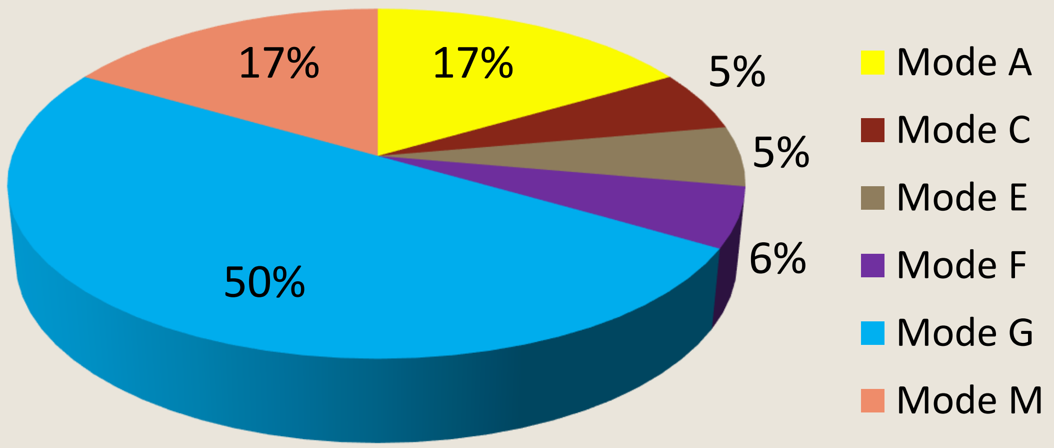


Column and Girder Failure Modes

Summary of Failure Modes in Column Samples



Summary of Failure Modes in Girder Samples



Mode G Failure at Various Ages

Bridge	Repair Age (Months)	Mode G Failures (%)
Bridge 2	26	50
Bridge 4	30	100
Bridge 5	55	50
Bridge 8	61	100
Bridge 7	74	100
Bridge 6	78	33
Bridge 1	82	0
Bridge 3	93	63

FRP Age and Strength Relationship, Mode G Failures

- The best fit trend line is given by the equation:

  Y=-0.0175X+3.4185

Where: Y= FRP strength in MPa, and X=age in months.

- The equation has a low correlation coefficient of 0.573.

Conclusions and Recommendations

- The in-situ condition assessment of FRP bond is important to determine the quality of installation and long-term performance.
- The long-term FRP wrapping performance in the eight selected bridges in the DFW area is good, but mixed, with 58% of the samples experiencing ASTM Mode G failure in the concrete substrate.
- About 31% of the samples failed in ASTM Modes C, E and F, and the non-ASTM Mode M defined herein. This could be due to:
    - improper initial storage, surface preparation or preparation/application of the epoxy and FRP.
    - age related environmental degradation.
    - Unfortunately, initial FRP application information is not available.

Conclusions and Recommendations

- The majority (83%) of column samples failed in the desired Mode G. Large scatter in the test results could be due to inadequate initial FRP application and/or core cut depth variations in the pull-off test.
- Girder FRP samples predominantly failed in Mode G (50%), less in proportion than that in column samples. The probable reasons are:
  - Greater chance of improper initial FRP application on girder surfaces. Application on girder surfaces is more difficult (due to various sides, change in angles between surfaces and accessibility issues) than that on column surfaces.
- The FRP-epoxy-concrete bond strength decreases with age in general. The test results with age are widely scattered around a straight line model (with a low correlation coefficient).

Conclusions and Recommendations

- The age of the initial FRP repair did not show consistent correlations with the percentage of test samples failing in Mode G.
- Strict adherence to the guidelines for the FRP wrapping installation must be made in order to achieve quality FRP-epoxy performance. Such steps include adequate surface preparation, FRP and epoxy combination selection, epoxy mixing, epoxy application on FRP and concrete substrate, FRP placement on concrete, finishing, epoxy curing and following limits on environmental conditions for installation.
- Quality control for the ASTM pull-off testing is also very important. Proper attention, needs to be paid to surface preparation, scoring through FRP/epoxy/concrete, selection and application of epoxy for dolly, dolly attachment to FRP surface, epoxy curing, and pull-off tester orientation and application.

Acknowledgment

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Thank you!

Questions?